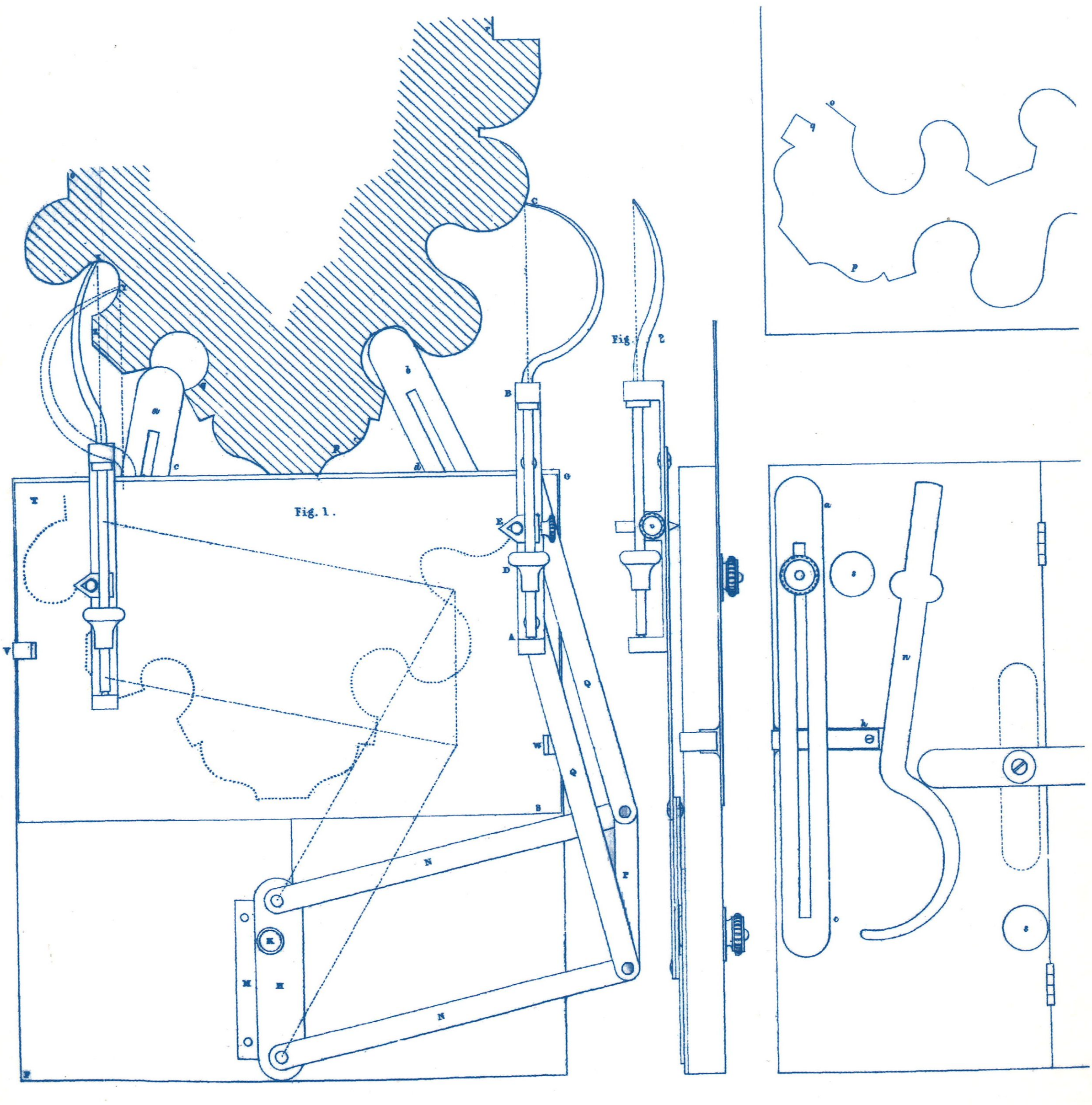
Robert Willis

Science, Technology and Architecture in the Nineteenth Century



Textos sobre Teoría e Historia de las Construcciones \ Texts on the Theory and History of Constructions

Colección dirigida por / edited by Santiago Huerta

M. Arenillas et al. (Eds.). **Actas del V Congreso Nacional de Historia de la Construcción**
F. Bores et al. (Eds.). **Actas del II Congreso Nacional de Historia de la Construcción**
A. Buchanan et al. (Eds.). **Robert Willis: Science, Technology and Architecture in the Nineteenth Century**
A. Casas et al. (Eds.). **Actas del I Congreso Nacional de Historia de la Construcción**
A. Choisy. **El arte de construir en Roma**
A. Choisy. **El arte de construir en Bizancio**
A. Choisy. **El arte de construir en Egipto**
A. Choisy. **Historia de la arquitectura.** (en preparación)
I. J. Gil Crespo. (Ed.). **Historia, arquitectura y construcción fortificada**
J. Girón y S. Huerta. (Eds.). **Auguste Choisy (1841-1909). L'architecture et l'art de bâtir**
A. Graciani et al. (Eds.). **Actas del III Congreso Nacional de Historia de la Construcción**
R. Guastavino. **Escritos sobre la construcción cohesiva y su función en la arquitectura**
J. Heyman. **Análisis de estructuras: un estudio histórico**
J. Heyman. **El arco de fábrica** (en preparación)
J. Heyman. **El esqueleto de piedra. Mecánica de la arquitectura de fábrica**
J. Heyman. **Equilibrio de estructuras de cáscara** (en preparación)
J. Heyman. **Geometry and Mechanics of Historic Structures**
J. Heyman. **La ciencia de las estructuras**
J. Heyman. **Teoría básica de estructuras**
J. Heyman. **Teoría, historia y restauración de estructuras de fábrica. 2 vols.**
J. Heyman. **Vigas y pórticos**
S. Huerta. **Arcos, bóvedas y cúpulas**
S. Huerta (Ed.). **Actas del IV Congreso Nacional de Historia de la Construcción**
S. Huerta et al. (Eds.). **Actas del VI Congreso Nacional de Historia de la Construcción**
S. Huerta et al. (Eds.). **Actas del VII Congreso Nacional de Historia de la Construcción**
S. Huerta et al. (Eds.). **Actas del VIII Congreso Nacional de Historia de la Construcción**
S. Huerta et al. (Eds.). **Actas del I Cong. Internacional Hispanoamericano de Historia de la Construcción**
S. Huerta (Ed.). **Las bóvedas de Guastavino en América**
S. Huerta (Ed.). **Essays in the History of the Theory of Structures**
S. Huerta (Ed.). **Proceedings 1st International Congress on Construction History**
J. Monasterio. **Nueva teórica sobre el empuje de las bóvedas** (en preparación)
J. R. Perronet. **La construcción de puentes en el siglo XVIII**
H. Straub. **Historia de la ingeniería de la construcción** (en preparación)
H. Thunnissen. **Bóvedas: su construcción y empleo en la arquitectura**
A. Truñó. **Construcción de bóvedas tabicadas**
E. Viollet-le-Duc. **La construcción medieval**
R. Willis. **La construcción de las bóvedas en la Edad Media**

Robert Willis: Science, Technology and Architecture in the Nineteenth Century

Robert Willis (1800-1875)

Robert Willis

Science, Technology and Architecture in the Nineteenth Century

Proceedings of the International Symposium held in Gonville and Caius College, Cambridge UK, 16th -17th September 2016

Edited by

Alexandrina Buchanan

James W. P. Campbell

Javier Girón

Santiago Huerta

Instituto Juan de Herrera

Escuela Técnica Superior de Arquitectura

Universidad Politécnica de Madrid

ISBN: 978-84-946000-0-5
Depósito Legal: M-31339-2016
Cubierta: Plate from R. Willis “Description of the Cymagraph for Copying Mouldings”, 1842
Frontispice: Photo of R. Willis (S. Huerta)
Fotocomposición e impresión:
Gracel, s. l. l.
28018 Alcobendas
Distribución y venta: librosjuandeherrera.wordpress.com

Contents

Introduction

Alexandrina Buchanan

"Robert Willis: Science, Technology and Architecture in the Nineteenth Century" draws together papers from a wide range of experts with the aim of reigniting interest in the work of the nineteenth-century polymath Robert Willis, whose writings shaped knowledge in fields as diverse as the study of sound, physiology, mechanism, construction and, especially, architectural history. The importance of Willis's contribution to these fields, although undeniable, has often been overlooked, in part because many of his writings have long been out of print and are hard to access, in learned journals or expensive folios, an obstacle we have tried to address through the "Willis Digital Library" on the robertwillis2016.org website. Looking at his work as a whole also reveals connections between his ideas, re-integrating his diverse interests and stimulating new links to be drawn between disparate disciplines.

Although Willis's biography may be familiar from his O.D.N.B. entry by our contributor, Ben Marsden and from my own *Robert Willis and the Foundation of Architectural History* (2013), its outline bears repeating. Willis was born in 1800, son, grandson and nephew of the then-celebrated, now notorious, Drs Willis, who treated George III during his bout of insanity. Growing up in Regency London, Willis early on showed an interest in machines, music and architecture. His first book (Willis 1821) was published anonymously when he was just 21, even before he had gone to University. His keen intellect and problem-solving ability was showcased in his study of the famous chess-playing "automaton", known as "The Turk" which had been displayed to wondering audiences all over Europe and the United States of America. Willis was the first to demonstrate that a full-sized player could be concealed within the base of the contraption —as later proved to be the case.

Whilst at Cambridge, Willis became part of a circle of pioneering young scholars including Charles Babbage (inventor of the computer), George Biddell Airy (who established Greenwich as the prime meridian) and William Whewell (who coined the term scientist). He produced a number of papers for this audience that proved fundamental to the study of the vowels, understanding the working of the larynx and the development of kinematics as a field of mechanics (Willis 1830a, 1830b, 1833). This led to his 1837 appointment as the Jacksonian Professor of Experimental Philosophy at the University. It was for his students that he wrote the *Principles of Mechanism* (Willis 1841); he also invented a form of apparatus with which he assembled models to demonstrate different relations of motions and the working of machines during the course of his lectures. The brilliance of his lecturing style led to his selection for a set-piece performance when Prince Albert paid his first visit as Chancellor to the University. He also became a lecturer at the Royal School of Mines in 1853, where he lectured to huge audiences of working men (and Karl Marx).

Alongside developing his scientific career, Willis had begun his lifelong fascination with medieval architecture. His contribution to architectural research was acknowledged through the 1862 award of the gold medal by the Royal Institute of British Architects. His 1835 book, *Remarks on the Architecture of the Middle Ages, especially of Italy* established a framework for the analysis of Gothic architecture which both helped to fuel the contemporary Gothic Revival and remains influential today. This was the book which transformed Ruskin's understanding of architecture from something essentially picturesque to an appreciation for construction, the rationale underpinning the *Stones of Venice*.

Willis's interest in construction led to his fascination with medieval vaults, particularly the complex rib vaults of late medieval England. His exemplary analyses tried to enter the mind of the medieval mason, showing how the most complex effects could be achieved by the simplest geometrical means. Nor were his structural interests limited to historic buildings: the 1849 report of the Royal Commission on the Application of Iron to Railway Structures was essentially Willis's work and identified the problem of fatigue which had led to a number of railway disasters.

Willis also developed a more historical approach to the study of buildings. In 1843 he became a founder member of the British Archaeological Association to whom he lectured on the architectural history of Canterbury Cathedral at their first congress in 1844. He went on to give similar lectures to the breakaway body, the Archaeological Institute, for whom he prepared papers on the majority of England's medieval cathedrals. Notable examples include monographic studies of Winchester, York, Chichester, Worcester and Lichfield which continue to be the starting points for anyone studying these buildings today. His method, re-

lating textual evidence with forensic stone-by-stone analysis remains fundamental to structural archaeology and medieval architectural history. His studies could inform contemporary restorations, as at Hereford Cathedral in 1841, where he argued against plans for an imaginative reconstruction of the Norman tower or at Chichester in 1861, where he defended the actions of the local architect after the dramatic collapse of the central tower and spire.

He was also able to reconstruct buildings he had never visited, solely from careful interpretation of texts and drawings; despite having never been to Jerusalem, his 1849 study of the Holy Sepulchre Church and the sequence of its buildings and rebuilding said all that could be said before the uncovering of new evidence through excavation in the twentieth century.

Sadly Willis did not complete a long-promised history of architecture, nor did he live to see the publication of his most substantial book, *The Architectural History of the University of Cambridge*, brought to press by his nephew John Willis Clark in 1886. As Willis's main heir and literary executor, Clark deposited the majority of his uncle's papers in the Cambridge University Library where they remain an important research resource, although others were distributed elsewhere and some are now lost.

Willis's writings are exemplary in the prismatic clarity of their prose and the quality of their illustrations, most of which he drew himself. They were widely read and admired across Europe and in America, by readers as diverse as Viollet-le-Duc and Edgar Allen Poe. They continue to reward the careful reader with ideas which remain as insightful today as when first put to paper. The range of disciplines and topics addressed by our contributors, and their international reach are tribute to the ongoing significance of his work.

Our collection includes chapters covering the full range of Willis's activities. It opens with James Campbell, whose chapter "Willis and Cambridge" reveals Willis's pathway through contemporary academia, a context in which his wide range of interests seems less extraordinary and their focus more explicable (see, for example, the contributions of Maconie, Marsden and Becchi). As Campbell emphasizes, it is important to recognize the huge gulf between the Cambridge of Willis's day and its modern incarnation; nevertheless, as a guide to its architecture, *The Architectural History of the University of Cambridge* remains unsurpassed.

The next chapter, my own "Willis and his Networks of Knowledge" looks at the social context of Willis's work, and what this reveals about Willis the man as well as Willis the scholar. New information about Willis's family throws further light on his commitment to practical engineering (see also Marsden's chapter) and raises questions about the role of Cambridge in educating engineers and the role of technical professionals in the so-called intellectual aristocracy of the late

nineteenth century. Behind the scenes, however, Willis was building up the teaching of this subject both outside and within the University, which in the years after his death became a significant centre for research and teaching in this more technological topic. Jacques Heyman, whose pioneering work on architectural geometry and mechanics (Heyman 2016) reverses Willis's focus on "apparent" rather than "real" construction (see discussion by Bressani and Guxholli), shows how the foundations established by Willis were built up over subsequent decades and uses this historical account as a springing point for suggestions about the future of education in this field.

Ben Marsden, the first scholar to offer a historical interpretation of Willis's contribution to the teaching of mechanics at Cambridge, here returns to the subject of Willis's mechanical science, which has often overlooked by comparison with his architectural scholarship. His chapter forms a companion piece to his 2004 article in the *British Journal for the History of Science* and takes the account onward into the 1850s and beyond, showing how Willis sought to make a practical contribution whilst retaining his own "gentlemanly" status. Still less well known than Willis's mechanical work is his contribution to voice synthesis, which as Robin Maconie's richly allusive essay suggests, needs to be understood within a contemporary context of invention, inter-cultural and animal communication, and experimental music, provoking fundamental questions about what it means to be human.

Although Willis's architectural studies have received more attention from historians, there remain discoveries to be made. Chris Elliott's essay on "Willis and Egyptian architecture" explores a series of unpublished notes to demonstrate that Willis was at the forefront of the study of this mode of building, despite his knowledge coming entirely from books.

When he was able to visit a building for himself, Willis was exhaustive in his efforts to understand the chronology of its erection and the consecutive sequence of designs. He recognized that the upper levels often contained some of the most useful clues and, despite the dark and difficulties of access, explored the furthest reaches in search of overlooked evidence. Toby Huitson, who has himself undertaken extensive study of the uses to which these spaces were put, reviews Willis's understanding of such evidence at the monastic cathedral of Worcester, in the light of previous historiography, the work of his immediate successors and current research. Not only is Willis's work shown to have continued relevance but —in contradiction of those who have condemned his writings as dry and unappealing— for those prepared to follow him into the arcana of architecture, Huitson reveals some unexpected rewards.

For his studies of Worcester and other monuments, Willis has been identified as "the father of structural archaeology" (Tatton-Brown 1989, 9) and Tim Tatton-

Brown, cathedral archaeologist at many of the monuments studied by Willis, here highlights Willis's work on Chichester Cathedral, where his research took on forensic significance after the collapse of the central tower and spire. Tatton-Brown shows how crucial Willis's work has been for more recent archaeological recording of the fabric and suggests that there remains room for further investigation of the many structural issues raised.

The Symposium would not have been possible without the expertise and enthusiasm of Santiago Huerta, whose encyclopaedic knowledge of the historiography of architectural construction discusses the scholarly context for Willis's study of gothic vaults, whose own contribution is also explored by Becchi and Girón. The 1842 essay emerges as the most internationally significant of Willis's works and it is entirely fitting that the present publication forms part of a series which includes the translation of Willis's article into Spanish (Willis, 2012), alongside translations of works it influenced, by Choisy and Viollet-le-Duc.

Willis's work was as pioneering in its use of graphical representation as in its research methods and terminological innovations. As well as the reconstructions by Jill Atherton which form an integral part of Tim Tatton-Brown's chapter, our Symposium benefits from three separate contributions Willis's drawings as their starting point. Antonio Becchi discusses the role drawing played within Willis's work, as a tool of communication and persuasion. He pays particular attention to Willis's geometrical understanding of mechanics in relation to his understanding of architecture, revealing the truth of the appraisal by Willis's nephew, John Willis Clark in his original D.N.B. entry: "He treated a building as he treated a machine: he took it to pieces; he pointed out what was structural and what was decorative, what was imitated and what was original; and how the most complex forms of mediæval invention might be reduced to simple elements." This basically geometrical approach, eschewing analytical methods, was nevertheless a weakness in relation to Willis's role in the Royal Commission on the Application of Iron to Railway Structures, here set in the context of international understanding of such problems.

In another masterly analysis of Willis's drawings, specifically his "heuristic approach" to the study and representation of vaults, Javier Girón examines the constructive drawing as it emerged as a genre across Europe, in the work of Willis, Viollet-le-Duc, Choisy and others. By comparing Willis's original drawings with published versions, Girón reveals Willis's decision-making regarding representational strategies. Also unearthed from the archive is evidence of direct contact between Willis and Viollet-le-Duc, throwing further light on the former's influence on the younger scholar (also discussed by Bressani and Guxholli). He shows how Willis employed the latest graphical techniques, which leads us to the work of Nick Webb, who offers a digital re-presentation of Willis's work on me-

dieval vaults, enabling the questions posed by Willis in 1841 to be reopened by modern scholars through the use of laser scanning and digital 3-D analysis.

Perhaps the area which has been least well covered in previous scholarship has been Willis's international influence (Whyte 2015, 269). This is mentioned by Becchi and Girón and our final chapters therefore look at three countries where Willis's work was read, translated and used by local scholars. David Wendland, another specialist in the study of vaults —both medieval and nineteenth-century— looks at Willis's reception in Germany, both in terms of research and in the context of the practical revival of Gothic styles. Simona Talenti, whose monograph on French architectural historiography in the nineteenth century (Talenti 2000) provides both an institutional and an intellectual account of developments in France, looks at his reception in France and at the less well known situation in Italy, the only country other than England whose architecture Willis scrutinized and discussed in any detail in print. As she reveals, mentions of his name are few but reproductions of his drawings are more frequent, albeit unacknowledged and unattributed. She also suggests other lines of investigation for evaluating connections between Willis and Latin scholarship: revealing an area ripe for future research. Finally, Martin Bressani, author of the most recent biography of Viollet-le-Duc (Bressani 2014), and Aniel Guxholli, explore the relationship between the two men whose ideas ran in parallel but whose career trajectories, publication records and ideologies were markedly different.

Writing on the study of vaults, Robin Evans observed that "Willis's ideas remain diffused to this day [...] though Willis himself is either buried in the footnotes or raised from the dead for other reasons" (Evans 2000, 225). Although footnote status should not be dismissed, what emerges from these contributions is a recognition that Willis's influence has remained unacknowledged for too long – a situation he surely would not have appreciated (see Marsden's essay and Buchanan 2013, 238). His contributions should be recognized for their ability to transcend their contemporary context, continuing to provoke new and important questions. Willis himself aimed both to stimulate new research which would modify his own conclusions and to be timeless in his collection of factual information (Willis 1845 and 1846). In this, our authors suggest he was eminently successful: his work continues to be discussed for its value to research today, not simply as evidence of a nineteenth-century frame of mind. Through his commitment to a scientific methodology, Willis made a contribution to a body of knowledge which could be challenged on empirical terms but has generally stood the test of time. What is equally clear is the extent to which his contribution was intellectual and practical rather than institutional or social —what is discussed in this volume is framed primarily in terms of ideas, not structural changes. This may account for his relative invisibility within modern histories of science and archaeology,

with their emphasis on social and environmental context. Vital though this is for understanding his contemporary contribution, Willis cannot be reduced to a product of his context.

Acknowledgements

The conference and proceedings would not have been possible without the support of James Campbell, Santiago Huerta, Javier Girón and Tim Tatton-Brown. We would also like to thank Caius College and the custodians of the buildings visited on day 2 for their hospitality.

Reference list

Bressani, M. 2014. *Architecture and the Historical Imagination: Eugène-Emmanuel Viollet-le-Duc, 1814–1879*. Farnham and Burlington, VT.

Buchanan, A. C. 2013. *Robert Willis and the Foundation of Architectural History*. Woodbridge.

Evans, R. 2000. *The Projective Cast: Architecture and its three geometries*. Cambridge, MA and London.

Heyman, J. 2016. *Geometry and Mechanics of Historic Structures*. Madrid.

Marsden, B. 2004. "The progeny of these two 'Fellows'": Robert Willis, William Whewell and the sciences of mechanism, mechanics and machinery in early Victorian Britain. *British Journal for the History of Science*. 37(4): 401–434.

Talenti. S. 2000. *L'histoire de l'architecture en France. Emergence d'une discipline (1863–1914)*. Paris.

Tatton-Brown, T. 1989. *Great Cathedrals of Britain*. London.

Whyte,W. 2015. Review of Buchanan 2013. *Journal of the British Archaeological Association*. 168: 268–9.

Robert Willis Bibliography

1821 *An attempt to Analyse the Automaton Chess Player* (London: Booth)

1830 On the pressure produced on a flat plate when opposed to a stream of air issuing from an orifice in a plane surface. *Transactions of the Cambridge Philosophical Society* 3: 129–40.

—— On the vowel sounds. *Transactions of the Cambridge Philosophical Society* 3: 231–68.

1832 Über Vocaltöne und Zungenpfeifen, *Annalen der Physik und Chemie*, 2nd ser., 24, 3: 397–437, Taf. 4–5.

1833 On the mechanism of the larynx. *Transactions of the Cambridge Philosophical Society* 4: 323–52.

1835 *Remarks on the Architecture of the Middle Ages, especially of Italy.* Cambridge: Deighton.

1838 On the Teeth of Wheels. *Transactions of the Institution of Civil Engineers* 2: 89–112.
1839 *Syllabus of a Course of Experimental Lectures on the Principles of Mechanism*. Cambridge. (Published in 1840, Cambridge: Pitt Press).
1841 *Principles of Mechanism*. London: Parker.
1842 On the Construction of the Vaults of the Middle Ages. *Transactions of the Royal Institute of British Architects* 1, Part 2: 1–69. Reprinted London: Royal Institute of British Architects, 1910 and in Minet 1973.
—— The characteristic interpenetrations of the Flamboyant Style. *Transactions of the Royal Institute of British Architects* 1, Part 2: 81–87.
—— Description of the Cymagraph for Copying Mouldings. *Civil Engineers and Architects' Journal* 5: 219–29, Pl. 9.
—— *Report of a Survey of the Dilapidated Portions of Hereford Cathedral in the year 1841*. Hereford: Thomas N. Webb. (Reimpr. en Minet 1973).
—— Ueber die Konstruktion der Gewölbe im Mittelalter. *Zeitschrift für Praktische Baukunst*: 192–222, Taf. 37–40.
1843 Sur la construction des voûtes au Moyen-Age. *Revue de l'architecture et des travaux publics* 4: cols. 3–14, 289–304, 481–507, Pls. 2, 11, 12.
—— Der Cymagraph, zum kopieren von Simswerken; von R. Willis, Professor aus der Universität zu Cambridge. *Dingler's Polytechnisches Journal* 87, 6: 454–459, Taf. 8
—— A description of the Sextry Barn at Ely, lately demolished. *Cambridge Antiquarian Society Quarto public. No. 7.*
1844 *Architectural Nomenclature of the Middle Ages*. Cambridge: Cambridge Antiquarian Society. Octavo Publications.
1845 *The architectural history of Canterbury Cathedral*. London: Longman, Pickering and Bell. (Reprinted in Minet 1972).
1845 History of the Great Seals of England, especially those of Edward III. *Archaeological Journal* 2: 14–45.
1846 The architectural history of Winchester Cathedral. In: *Archaeological Institute*, *Proceedings at the Annual Meeting of the Archaeological Institute ... at Winchester, September MDCCCXLV*. London: Longman, Brown, Green and Longmans. (Reprinted in Minet 1972).
—— Principles of Tools for Turning and Planing Metals. In: Ch. Holtzapffel, *Turning and mechanical manipulation. Vol. 2. The principles of construction...* London: Holtzapffel, Note AU, 991–996.
—— On a new form of tool-holder, with detached blades for turning or planing metal, and on a new mode of fixing down tools upon the slide rest. In: Ch. Holtzapffel, *Turning and mechanical manipulation. Vol. 2. The principles of construction...* London: Holtzapffel, Note AV, 996–1001
1848 The architectural history of York Cathedral, *Archaeological Institute*, *Memoirs Illustrative of the History and Aniquities of the County and City of York*. London: Archaeological Institute. (Reprinted in Minet 1972).

—— Description of the ancient plan of the Monastery ef St. Gall, in the ninth century. *Archaeological Journal* 5: 14–45.

1849 *The Architectural History of the Church of the Holy Sepulchre at Jerusalem*. London: Parker.

—— On the effects produced by causing Weights to travel over Elastic Bars. In: *Report of the Commissioners appointed to inquire The Application of Iron to Railway Structures, Appendix B*. London: Clowes, 181–214, Lams. 7–10 (Ap.B). Reprinted in: P. Barlow *A Treatise on the Strength of Timber, Cast and Malleable Iron, and Other Materials*. London: Weale, 1851.

1850 Revised edition, with additions, of: John Parker. *A glossary of terms used in Grecian, Roman, Italian, and Gothic architecture*. 5th ed. Oxford: Parker.

1851 *A system of apparatus for the use of lecturers and experimenters in mechanical philosophy, especially in those branches which are connected with mechanism.* London: John Weale.

1852 On machines and tools for working in metal, wood and other materials. In: *London.-III. Royal Society for the Encouragement of Arts, Manufactures and Commerce. Lectures on the results of the Great Exhibition*. Lecture, 7.

—— Class VI: Report on Manufacturing Machines and Tools. In: *Exhibition of the Works and Industry of All Nations. Reports of the juries on the subjects in the thirty classes into which the exhibition was divided*. London: Clowes, 194–205.

1853 *Crystal Palace Company. Grand organ: preliminary report to the directors* (con F.A.G. Ouseley y John Donaldson). London : Blades, East & Blades.

1856 On Machinery for Woven Fabrics. In: *Reports on the Paris Universal Exhibition*. London, 155–76.

1859 *Facsimile of the sketch-book of Wilars de Honecort, an architect of the thirteenth century* (with commentaries and descriptions by M.J.B.A. Lassus and by M.J. Quicherat ; translated and edited with many additional articles and notes by Robert Willis). London: Parker.

1860 A Westminster fabric roll of 1253. *Gentleman's Magazine* (July to December): 293–99. Reprinted in G.G. Scott, *Gleanings from Westminster Abbey*. Oxford and London: Parker, 1863, Appendix, 231–52.

1861 *The architectural history of Chichester Cathedral*. Chichester: William Hayley Mason. (Reprinted in Minet 1972).

—— On the architectural history of Chichester Cathedral and on the fall of the spire, *Papers read at the Royal Institute of British Architects, Session 1860–61*, 231–8.

—— On foundations of early buildings, recently discovered in Lichfield Cathedral. *Archaeological Journal* 18: 1–24. (Reprinted in Minet 1973).

1862 "Address", British Association for the Advancement of Science, *Report of the Thirt-Second Meeting of the british Association for the Advancement of Science; Held in Cambridge in October 1862*,li–lxi. Also published separately.

1863 The architectural history of the cathedral and monastery at Worcester. *Archaeological Journal* 20: 83–132, 254–72, 301–18.(Reprinted in Minet 1973).

—— The crypt and chapter house of Worcester cathedral. *Transactions of the Royal Institute of British Architects* 13: 213–30. (Reprinted in Minet 1973).
1865 The architectural history of Sherborne minster. *Archaeological Journal* 22: 179–99.
1866 *The Architectural History of Glastonbury Abbey*. Cambridge: Deighton, Bell.
1868 The architectural history of the conventual buildings of the monastery of Christ Church in Canterbury. *Archaeologia Cantiana* 7: 1–206 (reprinted as a book, London: Taylor, 1869).
1870 *Principles of Mechanism*. 2nd ed. London: Longmans.

Posthumous works

1886 *The Architectural History of the University of Cambridge and the Colleges of Cambridge and Eton.* (Published, revised and augmented by John Willis Clark). Cambridge: Cambridge University Press. (Reprinted, with preface by David Watkin, Cambridge, 1988).
1888 *Extracts from the Second Edition of Principles of Mechanism*. London.
1972 *Architectural History of some English Cathedrals*. 2 vols. Chicheley: Paul B. Minet.
2012 *La construcción de las bóvedas en la Edad Media*.Madrid.

Willis and Cambridge

James W. P. Campbell

Wandering around Caius College Cambridge, today it is easy to get carried away and imagine that we are seeing the world just as Robert Willis experienced it. This paper seeks to correct that delusion. Cambridge has changed a great deal since his time, not just physically, in terms of the very buildings that Robert Willis and his nephew John Willis Clark so carefully recorded in their *Architectural History of the University of Cambridge,* but also socially. The University today and its colleges are very different from the way they were in Willis's day. The purpose of this paper is thus twofold: first to provide a picture of what Willis's Cambridge was like, and secondly, to show what has changed and thus most importantly what is missing from that great work *The Architectural History of the University of Cambridge.* There is perhaps no better place to start than with the physical setting of Willis' s own college, Gonville and Caius (always known simply as "Caius").

Caius College in Willis's day

The college that Robert Willis arrived at as a student in the summer of 1821 was physically very different from the college we see today. Many of those changes were made in Willis's own lifetime. Others happened after his death in 1875.

At the time Willis first entered Caius, the college consisted as it does today, of three courts: Caius Court, Gonville Court and Tree Court. The oldest buildings had been erected between 1393 and 1441 forming Gonville Court (Willis and Clark [1886] 1988, 166–169). It was a tiny court but at its original foundation the

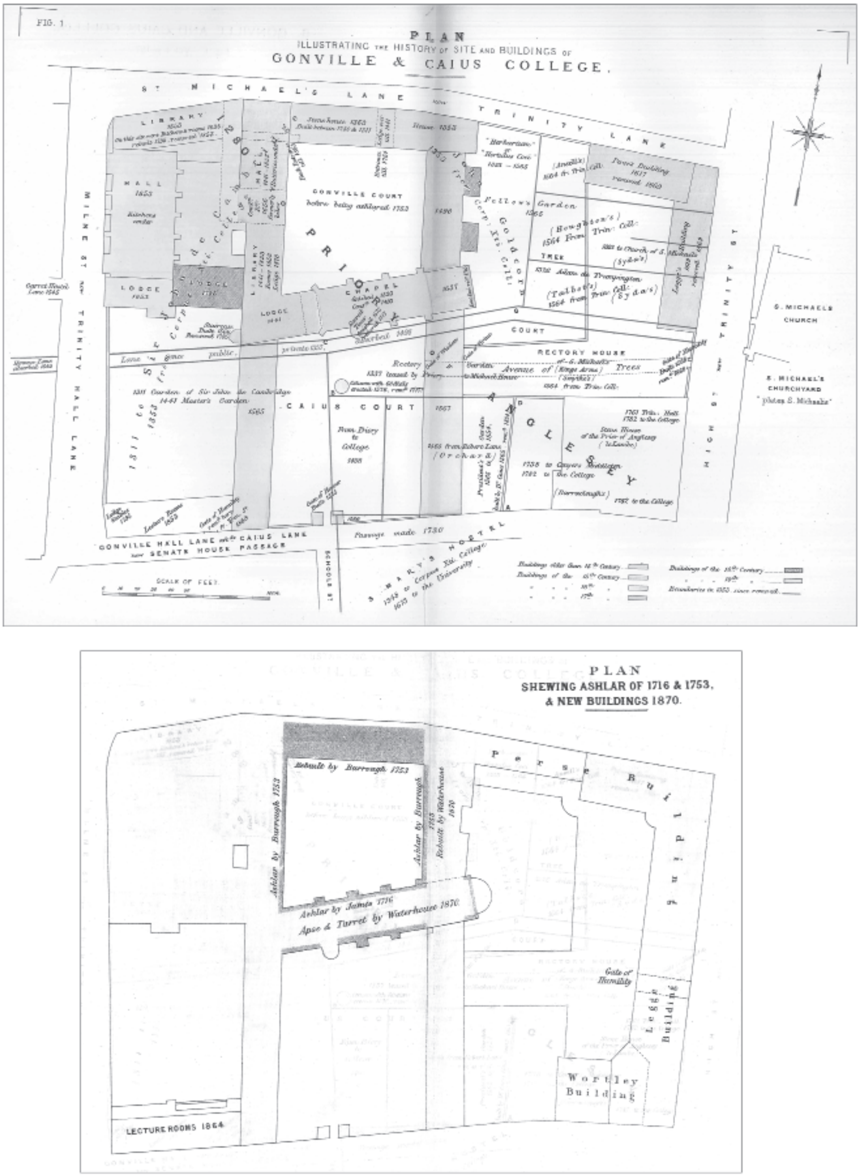


Figure 1

The plan of Gonville and Caius from Willis and Clark, *The Architectural History of the University of Cambridge* vol. 4 plan 8 (courtesy and thanks to of A. Buchanan)

college only consisted of a Master and four Fellows for whom it would have been spacious (Willis and Clark [1886] 1988, 170). Exactly what the court looked like in the Middle Ages when originally built can only be guessed at from Loggan's print because the East and West ranges of the court had been almost entirely rebuilt by James Burrough in the 18th century, between 1751 and 1755 and the North range being rebuilt by Tompson in 1755 (RCHME 1959, 76). It was these eighteenth-century stone re-facings with their sash windows that Willis would have known and that is what we still see today. Willis had rooms in this range in C and D but the staircases have since been replaced (Buchanan 2013. 31; RCHME 1959. 77). The college had originally been entered through a gatehouse (Fig.1) in this court but that had been removed in the 18th century (Willis and Clark [1886] 1988, fig.2 and 170). The Medieval Hall (erected in 1441) occupying the Northern-part of the Western range had been given a radical makeover by John Soane in 1792. He had provided the Hall with a shallow plaster vault below the original Medieval roof timbers (a plain collar beam roof) (Willis and Clark [1886] 1988, 197). The library formed the southern part of this range on the first floor. All of these internal spaces have been swept away although an reconstruction of Soane's vault has been reinstated in the Senior Combination Room relatively recently (Bradley 2014. 108–109). It is fair to say that most of the interiors of this court today would be barely recognisable to Willis. Salvin's Dining Hall (1853) was done in his lifetime, long after he left, but in time for Clark to include it in the *Architectural History* (p.197).

The second court, known as Caius Court, had been created by Dr Caius who transformed the college in the sixteenth century. It consisted of two new wings creating an open court, the southern side being formed by a gate and a low wall. Caius was at great pains to leave the Court relatively open on the south side so that it should enjoy the sunshine and went as far as legally protecting this side from being over shadowed (hence the break in the buildings on the other side of All Saint's Passage). He added a new entrance through Tree Court so that the members of the college now passed through a Gate of Humility (originally from the High Street but since moved to the Master's garden and badly damaged by time and poor repair), and then the Gate of Virtue, entering Caius court through the Gate of Wisdom, while on the south side they passed out through the Gate of Honour, the most spectacular of the gates, to Senate House passage. The last gate was created in a perfect classical style, almost certainly based on engravings from Fra Giocondo's *Vitruvius* published in 1511 (Bradley 2014, 105). Of the three Courts, this is the least changed since Willis's undergraduate days (Fig.2).

The third court, Tree Court, however, is so entirely different from Willis's time as to be virtually unrecognisable. When Willis arrived in 1821 he would have passed through a small gate (the Gate of Humility) into a walled avenue.

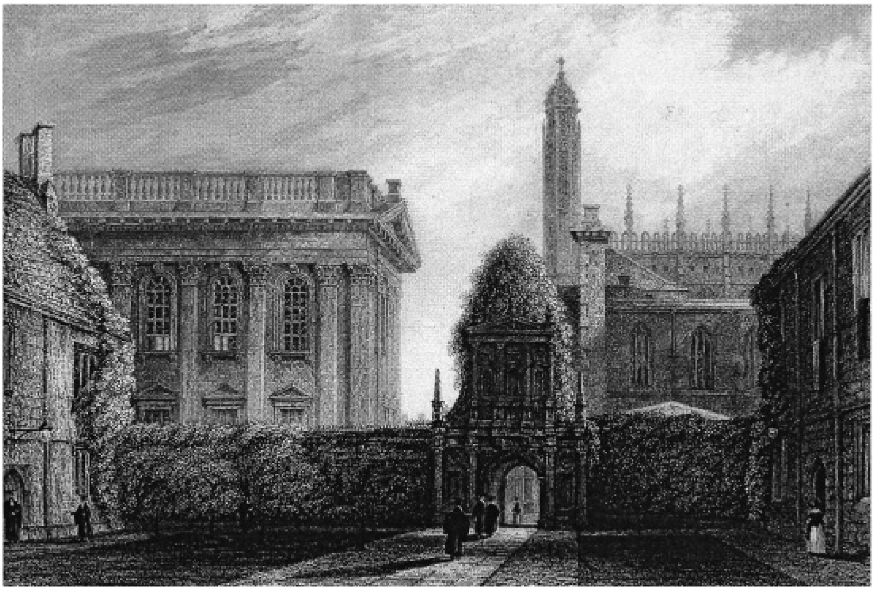


Figure 2
The Gate of Honour as it existed in Willis's day, somewhat overgrown, without the University Library behind (from Cooper [1860] 2012, 96–97).

On the left (South side) were the rear gardens and backs of various private houses that overlooked the square in front of the Senate House on the other side. The college front onto the High Street (now Trinity Street) was formed by the L-shaped Perse and Legge Buildings, a range of lodgings built in 1615–16 on three storeys that can be seen clearly in the Loggan's view. Today a larger courtyard is created by the huge ranges of Waterhouse's new front to the college added in 1868–1870 (Bradley 2014, 110). In Willis's time this court was lower and better lit and would have had an altogether more domestic feel. Loggan gives us a good impression of this (Fig.3).

This then was the college that Willis entered: it was much more modest than the one we see today. It was housing far fewer people. Those that lived in it thus enjoyed quite spacious accommodation. This is because of the much smaller size of the college and the University in 1800.

A Question of Size

It is incredible to think that at the beginning of the nineteenth century there were just two Universities in England: Oxford and Cambridge. There were none in

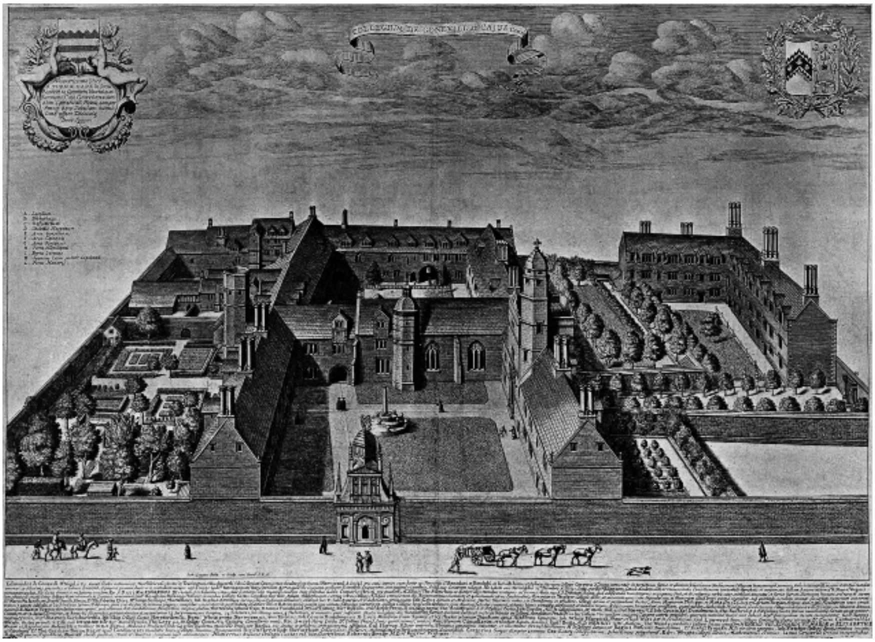


Figure 3
Loggan's print of Caius in the late seventeenth century, from David Loggan *Cantabrigia illustrata* (Cambridge, 1690)

Wales but Scotland had five (Frijhoff 1996, 78, table 2.4). This can be compared to their relative populations, with England and Wales numbering 9.25 million and Scotland 1.5million (Frijhoff 1996, 78). Part of this can be explained by the nature of the courses on offer. Since the beginning of sixteenth century in England the Inns of Courts had held the monopoly on the practice of Common Law, thus although Law was taught in Oxford and Cambridge it was still necessary to pass on to the Inns of Courts for legal training if you wanted to practice in the normal courts. Many chose to bypass the Universities altogether and go straight to the Inns. Medical training was better elsewhere and the subjects one could study were extremely limited. Indeed lack of call for University training for any profession in England and Wales in this period is reflected in the numbers of people enrolled.

Today Cambridge has about 11,800 undergraduates in residence (Cambridge University Website, 2016a). In 1801 and 1811 there were just 800 representing half of all the students in England. In 2015 there were a staggering 1.7 million students doing undergraduate degrees in the UK (Higher Education Statistics

Website 2016). 114 BA degrees were awarded in Cambridge in 1800 and 240 in 1833 (Searby. 1997. 68). Today there are about 3500 each year (Cambridge University Website, 2016b). The number of colleges has only doubled but the size of the University has increased over 1400% just in undergraduate numbers. Graduate students numbers were tiny in Willis's day but now rival undergraduate numbers at about 7000 (Cambridge University Website, 2016b)

The college populations were correspondingly smaller in the 19th century compared to the present day. Caius today has 571 undergraduates, 35 Masters students and 131 PhD students (Cambridge University Website, 2016). In 1795 Caius had 36 students and 27 Fellows (Searby, 1997. 272). By 1850 the numbers of Fellows had only risen to 30 but the number of undergraduates had gone up to 110. (Searby, 1997. 728). Although these numbers would rise still further in the next few decades they remained incredibly low by modern standards. In the whole University there were just 409 college Fellows (including the Masters) and 736 undergraduates in 1795, the number of Fellows remaining roughly the same but the overall numbers of students rising to 1753 (Searby, 1997. 728). There was thus no escaping the fact that the University was by modern standards incredibly small and Caius was a tiny institution.

This relatively small size had an important effect on the way the colleges like Caius were inhabited. Today most students in Caius live in modern halls of residence divorced from the main part of the college. Only a relatively small number have rooms in the college itself. A large number are across the road in St Michael's Court which is pleasant courtyard hidden behind St Michael's church (Bradley 2014, 110). The rooms are entered from this courtyard and are above the shops overlooking the streets. Further blocks of modern accommodation are on West Road. Harvey Court was designed by Sir Leslie Martin and Patrick Hodgkinson and built in 1960–62 while the snaking Stephen Hawking Building is more recent still, designed by Donald Insall and Partners and completed in 2005–6 (Bradley 2014, 336–37). The college that Robert Willis entered in 1821 was smaller than the college today, which allowed him to live on site in very elegant sets of rooms, consisting of a separate living room, study and bedroom. His life was centred in the college entirely, the more so because the way the University taught was very different from today.

Being a student in Willis's time

Just as it was for numbers so it was for courses of study: Cambridge provides the illusion of forever being the same, but in fact the University has changed continuously throughout its existence. For instance, since the 1980s Cambridge has gone from an entirely state-funded institution to one where all the students pay

fees, albeit mostly in the form of loans from the Government. This paying of fees is in some ways a return to the system that operated in Willis's time (Searby 1997. 76–81). In the seventeenth-century undergraduates had entered the University at about the age of fourteen but the age had gradually risen and by the end of the eighteenth century it was little different from today, the typical undergraduate entering at 17 or 18 years of age. There were no government examinations on which to judge the merits of candidate entering the University. Students were expected to come up in the Easter term before they matriculated and thus to be in residence 10 terms. The traditional examinations in the University had been oral disputations (Searby 1997.156–67). These had been supplemented by written examinations in the 18th century, the questions being given to the students orally by the examiners in the Senate House where the examinations were held. By the 1790s printed examination papers had become the norm (Searby, 1997. 76–81).

Subjects taught

Today students arrive in Cambridge having applied to study a certain subject. They may be embarking on a Mathematics Degree in which case they will be taught in the Mathematics Faculty, or they may be taking a Classics Degree and they are taught in the Classics Faculty. When Willis arrived in Cambridge, although there were theoretically Degrees in Law, Theology and Medicine as well as the Bachelors of Arts Degree, in practice very few students sat for the other degrees. There was thus only one degree taken by a vast majority of students and that was the Bachelor of Arts (BA) Degree. This was tested primarily and perhaps surprisingly to modern eyes by a written examination in Mathematics (Searby 1997. 1–6, 76–81). Classics was only examined as an option after a successful pass in the Mathematics examination. This was in sharp contrast to Oxford where the emphasis was placed on Classics first and Mathematics second. The influence of Isaac Newton can be seen as being responsible for this split and while this was undoubtedly beneficial for the encouragement of mathematics and science at Cambridge over Oxford, the influence of Newton was also something of an impediment (Searby 1997, 2–4, 166–186).

This favouring of Newton meant that Cambridge was behind continental advances in mathematics. Newton's *fluxions* were geometric in their understanding and resulted in essentially geometric proofs. The continent, however, had taken on Leibniz's algebraic notation for calculus and the resulting analytical school of mathematics had made enormous advances in the 18th century (Searby 1997, 2–4, 166–186). It was in Willis's time as an undergraduate that the great battle in the University was being fought between the younger Fellows eager to advance the cause of analysis against the Newton and Euclidean school represented by the

older Fellows who knew nothing else. Analysis won out. Willis's own mathematical understanding must be viewed in this context if it is to be understood. He sits at the cusp of the two traditions and his education was accordingly probably mostly in Newton's methods rather than continental ones. However compared to modern teaching it is difficult to gauge how much teaching Willis would have received.

Teaching in Faculties and Colleges

The modern undergraduate in Cambridge is admitted by their college to study a certain subject. They live in the college or at least in college-owned accommodation and they can use the college's facilities. In addition they will have been assigned by their college a Director of Studies in their chosen subject. These are usually, but not necessarily, a Fellow of the College. The Director of Studies is then responsible for monitoring their studies throughout their period in Cambridge and for assigning supervisors who see them individually or in small groups weekly throughout their period in residence. These supervisions are what distinguish Oxford and Cambridge from most other British Universities. However the students will be expected to follow the syllabuses and courses set out by their Faculties. Each Faculty has a set of buildings that hold its administrative staff and teaching facilities (lecture halls, seminar rooms etc) and in the sciences and technology will also contain all the teaching workshops and laboratories that the syllabus requires. Most colleges today offer all the subjects in the University but it is the University that provides most of the facilities. It is the University that receives the fees and gives a portion of the fees to the individual colleges. The modern University is composed of 30 colleges and a very large number of University Faculty buildings spread across the town and stretching into the countryside.

In Willis's day the University had virtually no facilities or buildings of its own. There was the Senate House and there were the small courtyards behind it which housed the University Library and a few lecture rooms. And there was a lecture room shared between the Jacksonian Professor and the Professor of Botany on the edge of the then Botanical Garden which lay to the North of what is now Pembroke Street. Most of the teaching, that there was, was done in the colleges. Colleges put on lectures for their students. Colleges appointed Tutors to look after their students who did very much what a Director of Studies does today in terms of organising supervisions (Searby 1997, 118–129). But the Tutors also took the fees, which they used to pay the college and the supervisors (called then "assistant tutors"). The quality of the teaching provided seems to have varied hugely. Some students complained that they got little more than the college lectures while others

seem to have been well taught by energetic Fellows. Many however if they wished to do well resorted to employing private tutors to assist them in their preparation for the University examinations (Searby 1997, 130–133).

Types of Student

Students in Willis's day were divided into different types. England has often been accused of being obsessed with coial class and this was more true in the nineteenth century than it is today. Students were either noblemen, Fellow Commoners, pensioners or sizars. Noblemen were peers of the realm and 'persons related to the King's Majesty by consanguinity or affinity'. They paid £10 a quarter for tuition, ate on High Table with the Fellows and were given a MA degree after two years of simply residing in the University without any formal examination and bypassing the BA degree entirely. Below them were the Fellow Commoners. They were sons of the rich. They paid £5 and were also allowed to dine on High Table. They had a bad reputation for misbehaviour and might be excused lectures and examinations as long as they were content with the Ordinary BA degree rather than honours. The majority of students were Pensioners. Those that received help from the college were Scholars. They came from the middle Classes, from families with professional or clerical backgrounds. The expansion of the Middle Class in the nineteenth century accounts for the rise in the student numbers during the early decades of the century. They paid £2 10s a quarter. The lowest group were the sizars. In return for tuition and board sizars paid only 15s a quarter. The duties that they carried out used to include waiting at table and acting as valets for the Fellows but these were being phased out in this period and by 1850 had been abolished everywhere. They continued merely as a form of scholarship for those from poorer backgrounds. Perhaps not surprisingly the Pensioners and Sizars were the classes of students most likely to work hard and be diligent in their studies in the hope they might be graded highly in the examinations.

The University was a male domain. Women's colleges were created in the 1870s but their relationship to the University was unusual and women were not able to take degrees until 1948 (Leedham-Green 1996, 175–179, 192–193). In Willis's day the University was also strictly conformist in religious outlook. All students who entered had to profess the Anglican faith. No Catholics, Jews or Muslims or any other form of religion was allowed (Leedham-Green 1996 136). Chapel was compulsory and remained so throughout the century, both Fellows and students being expected to attend twice a day, just as they were expected to be present at meal times (Searby 1997, 268–276). The colleges were firmly locked and barred at night. Colleges remained locked into the 1990s although the

time got later and later until eventually with the invention of electronic locks they became accessible to members 24 hours a day.

Many students did not work but those that did faced a gruelling set of examinations in the early 19th century. The object of the examinations was to produce a ranking of all candidates from the brightest to the lowest admissible pass. The examinations were held in the cold of January over a series of days with the better students being retained and the less good released after a series of increasingly difficult papers. Eventually the examiners would decide on a winner. The student declared top of the tripos was called the Senior Wrangler. Below honours students were graded as Wranglers, Senior Optimes and Junior Optimes (Leedham-Green 1996, 125).

Willis joins the University

Robert Willis entered Caius in 30 June 1821 (Buchanan 2013, 31). His father, Robert Darling Willis (1760–1821) was a doctor in a prominent family of doctors, specialising in the care of the insane: they looked after George III (Bucahnan 2013, 13). Although Robert Darling Willis's position at court gave him considerable prestige and he lived in London in Hanover Square, he never relinquished his connections with Cambridge where he was a Fellow of Caius (Bucahnan 2013, 13). He remained unmarried so our Robert Willis was born out of wedlock and mother and son were cared for financially but lived separately at 17 Buckingham Street (Bucahnan 2013, 14). Robert was taught at home only going briefly to school in Kings Lynn just before he went up to Cambridge. The reason for his slightly late entry into Cambridge is not known but it is generally assumed that he waited until his father was no longer alive before going to Caius to save embarrassment. His inheritance was more than enough to cover the fees and he entered as a Pensioner. His first rooms were C1 Gonville Court and later as a Fellow he would move to D2 (Buchanan 2013, 31), Figure 4. Willis graduated as 9th Wrangler in 1826 placing him top in the college and he was rewarded with a Fellowship (Marsden 2004).

Becoming a Fellow

The process of becoming a Fellow of a Cambridge college today is understandably a something of a mystery to outsiders. There are in fact not one but a number of different types of Fellow. To complicate matters further there is no established terminology, the words used varying from college to college. In general however today there are Fellows who are appointed entirely by the colleges (so-called College Teaching Officers or CTOs) and those that are appointed from the Uni-

Figure 4
The North and East sides of Gonville Court with its 18th century refacing, since much repaired. Willis lived on the North side (left) (Author)

versity Lecturers (so-called University Teaching Officers or UTOS). Colleges will try to appoint University Lecturers as Fellows. When a University Lectureship becomes vacant through the leaving or retirement of its previous incumbent it is advertised internationally. The University Faculty interviews and appoints the individual. The name and CV of the new appointee is then circulated to the colleges. They in turn decide whether they need that expertise within the college and if so they invite the candidate to apply. They are interviewed by a panel of the Master and Fellows who then make a recommendation to the whole Governing Body (the complete Fellowship) and if successful the candidate is voted in and becomes a Fellow. There is no requirement in Cambridge for University Lecturers to join colleges. There are thus today University Lecturers who are not college Fellows, either because they choose not to be or because no college has chosen to offer them a Fellowship. Those who do become Fellows are generally appointed until retirement subject to them continuing to hold their University Post. It is difficult for colleges to recruit enough teachers in some subjects from the limited number of University Lectureships available and in these cases the college may choose to pay entirely for its own teacher in that subject. These are

the so-called College Teaching Officers and they typically hold office for a limited tenure 3–5 years but easily renewed. In addition the College may offer a limited number of Research Fellowships which are openly advertised and designed to give young academics a chance to publish without teaching responsibilities. They are generally for 3–4 years and not renewable.

The benefits of being a Fellow in a college vary enormously in the University today. Some colleges offer generous salaries. Most colleges offer rooms. Non-married Fellows are often entitled to live in college free of charge or for a nominal rent. All colleges encourage their Fellows to lunch or dine and hold feasts throughout the year. Fellows are generally members of the Governing Body and collectively responsible for the running of the college. It has become increasingly common for those undertaking various administrative roles to come from outside the college and to be appointed Fellows as part of that role. Thus Senior Bursars are generally experienced financiers with no academic or teaching role who are made Fellows so they can be on Governing Body and manage the college finances. Masters of colleges are also increasingly appointed from outside academia and recruited because they can help in fund-raising.

All of this would have been almost entirely unrecognisable in Willis's day. For a start there were only 16 colleges. The nineteenth-century Fellow was an entirely different creature from his modern counterpart. Perhaps the first and most important difference was that Fellows in Willis's day were all male. Despite the fact that they had all studied maths, a great number of them were still required to be in holy orders. All of them had to be Anglican. Not only Muslims, Jews and Catholics were excluded, but Baptists, Methodists, Quakers, Lutherans or any other Protestant non-conformists. The 1856 Act only allowed non-Anglicans to enter the University (Brooke 1988, 272). All University posts were still restricted at that date, a fact that did not change until 1871 (Leedham-Green 1996, 160).

Not only were Fellows Anglicans they had to remain unmarried. The requirement for celibacy was absolute. If a Fellow wished to marry he had to resign his Fellowship. This aspect of Fellowship had long been discussed and in 1765 a Grace had even been proposed to the University to abolish it, but it had been defeated. It was to be challenged again in 1852 (Leedham Green 1996, 157) and finally made possible in 1860 (Leedham Green 1996, 161). Caius was the first college to adopt it (Brooke 1998, 272).

Thanks to these various requirements, most Fellows held their Fellowships for relatively short periods, usually for no more than 11 years (Searby 1997, 106–109). A Fellowship was, for most, something you did after graduating, but before marrying. It was thus predominantly a young man's occupation, with a smaller number of Fellows who had no wish to marry remaining in college for life.

The Fellows were entirely college appointments; that is there were no such things as University Lectureships before the 1850s (Leedham Green 1996, 156) so the colleges had to appoint the Fellows from those qualified, typically looking to those who had recently taken the University examinations. The statutes varied widely and imposed further restrictions. Some Fellowships were appointed by Bishops or individuals outside the college, very often from lists drawn up by the college (Searby 1997. 94–106). Some were at the whim of the Master. Some were even appointed by the descendants of benefactors. Sometimes there were restrictions on the origins of Fellows. They might have to have been students in the college or might have to come from a particular part of the country. Caius, for instance, had to have three Fellows from Norfolk and 3 had to be from Norwich (Searby 1997, 99).

Masters of Colleges were again subject to differing rules in different colleges. Most were elected from within the Fellowship, but some were in the gift of outsiders, or the Crown. The Masters of the Colleges were unique in their colleges in being exempted from the rule of celibacy and free to marry. This led to the strange arrangement whereby the head of the college lived in usually quite lavish quarters often with a wife and family in the college surrounded by Fellows and students who were forbidden from marrying and at least theoretically celibate.

All Fellows enjoyed free meals. They were given rooms in college that they could live in or rent out as they saw fit. They governed the college, often in collaboration with the scholars but were definitely ruled by the Master. Perhaps most importantly Fellows were entitled to a dividend, a portion of the income of the college endowment. In the cases of many colleges by the 19th century this had become quite considerable. Once appointed their duties were light. They could become tutors if they wished or take on the roles of bursar or librarian, but in general they were left to their own devices. There were many cases of abuse of the privileges: Fellows retaining their Fellowships but rarely appearing in the college at all or doing the bare minimum of duties (Searby 1997, 100–103). Many colleges attempted to crack down on such behaviour with varying degrees of success. When they had found better posts elsewhere Fellows moved on. Sometimes they became vicars of college livings (the colleges typically controlled a number of churches and paid for their upkeep to give ex-Fellows a place to go to). Most colleges retained the requirement for Fellows to take holy orders within a few years of accepting the post.

One of the advantages of the system was that as Fellows left the colleges to get married or pursue careers, they left spaces for new Fellows to join, so in general each college would appoint 1 or 2 new Fellows each a year. The overall number of Fellows was generally fixed by Statute despite the fact that the number of students increased in the first few decades of the century. Selection of new

Fellows was largely on success in the University examinations and in this sense it was generally and increasingly meritocratic. Normally only Wranglers high up the list could expect to get a Fellowship.

Once appointed Fellows were expected to give lectures in their colleges. Indeed this seems to have been the main mode of teaching. With so few students in the whole college and every student following the same basic course of study this was of course not a tremendous difficulty and it made sense to group the 5–10 students together in each year and lecture them.

University Professorships

While there were no University Departments or Faculties, there were University Professorships. At Oxford it had at one time been the case that University Professors were barred from being Fellows of Colleges but no such bar existed in Cambridge. The University Professorships were entirely separate from the colleges and the holders were bound by the terms of their Professorships to give lectures to the University as a whole and often to those outside it as well. It was possible to be Professor and a Fellow of a College or a Master of a College, but it was equally possible to hold the post without any college connection. Professors, unlike Fellows, could be married, so it offered one way for academics to remain active within the University if they wished to have a family. The terms were rarely onerous and often only required the Professor to come to Cambridge intermittently and deliver lectures in one of the three University Terms a year (Leedham Green 1996, 113). As a result University Professors sometimes lived outside Cambridge, turned up to give their lectures and went away again. Others were Masters or Fellows of colleges and played a very active role in running the University. The problem for the University Professors was the lack of teaching space and indeed of living accommodation and the generally low pay, which meant that Professors had to have a second source of income to survive (Searby 1997, p.205).

Willis's experience

This then is the world that Willis entered as a Frankland Fellow in Caius in 1826 (Buchanan 2013, 37). He was duly ordained a deacon and priest in Ely in 1827 and became Dean of his college. He got his MA in 1829 (Buchanan 2013, 37). There was no examination, the qualification being nothing more than having been in Cambridge for seven years. He was made Steward, a job that generally involved watching over and managing the food and wine and became a Foundation Fellow(Buchanan 2013, 37). His decision to marry Marianne Humfrey, the

daughter of a local architect and councillor, in 1832 meant he had to resign his college Fellowship and he looked around for another post, trying out for the office of University Registrary (Buchanan 2013, 37). As Buchanan has noted, it is probably good that he was unsuccessful because this post would have given him less time for academic pursuits. His private wealth must have been crucial in sustaining him through the next few years (Buchanan 2013, 38). He made himself busy with research and publishing, no doubt in the hope of standing for a suitable post if it came up. Professorships were decided by election and it is a tribute to Willis's diplomatic and political skills that he managed to get elected to the Jacksonian Professorship when it fell vacant in 1837. It is clear from the various accounts of the time that he was a brilliant lecturer. The Professorship now gave him a permanent position in the University and thus in society. It would have been unsustainable without his private income. He lectured in the autumn (Michaelmas) term virtually every day, but the audiences were small. Otherwise he was free to pursue his research. His appointment as a lecturer in the Metropolitan School of Science in London and indeed his ability to divide his time between houses in London and Cambridge, can only be understood in relation to the responsibilities of Cambridge professors at the time. Nonetheless it is clear that Willis was a person of great energy who used the time he had available to get involved in a huge range of things. The prestige of the Cambridge professorship was helpful in opening doors, while its relatively light responsibilities enabled him to get involved in a huge range of activities.

Conclusion

Willis's entry in the Dictionary of National Biography (Marsden 2004) describes him as "engineer and architectural historian". Although that is how we might view him through modern eyes, I doubt Willis would have recognised the description. It is likely he would have described himself as an academic and as his contemporaries felt free to look into a broad range of subjects, so did he. The idea that he founded engineering in Cambridge is far fetched. There was certainly no school of engineering until well after he died. He followed his predecessors in what he taught, developing the subject on his own way. It was only relatively late in life that he began the massive task of compiling an architectural history of the University of Cambridge and it was as much due his nephew as his own endeavours that the book ever saw the light of day. The range of his publications seems broad in modern eyes but his teaching duties, which he took seriously, were relatively slight and left ample time for him to study what he liked. Willis was undoubtedly an extraordinary man who achieved a great deal but, as all of us, he was a product of his time, a time very

different from our own and it is only in that context he can be understood. His private wealth supported him and allowed him to study. His Professorship gave him status and position.

The contribution of An Architectural History and its limitations

If we turn now to Willis's *Architectural History of the University of Cambridge,* the book remains an extraordinary achievement. As Buchanan pointed out, a great deal of the work was down to his nephew John Willis Clark. Willis did not start the project until comparatively late and seems to have added to it gradually. It began with a lecture in Cambridge to the Archaeological Institute on the subject in 1854 (Buchanan 2012, 150; Buchanan 2013, 345). The shortcomings of Willis's work are in many ways self-evident and have been discussed by Buchanan and Watkin (Buchanan 2013, 322–356; Watkin 1988 ; Buchanan 2012). As they note, Willis and Clark had limited interests in social history and the book is generally poor in explaining the changing use of the buildings through the ages (Watkin,1988 XV). What Willis does do is try to trace the development of the buildings from the Middle Ages and here the plans (vol. IV but not included in the cheaper later reprints) are particularly useful. Here we see Willis at his best, tracing ownerships, establishing the order of changes and plotting them carefully. In this we see what we might call "the Willis method" in action, Clark bringing to the party his painstaking documentary research.

It is interesting to contrast the book both with the later inventory by the Royal Commission on the Historical Monuments of England (1959) and with the latest revision of Pevsner (Bradley 2014). The Royal Commission volumes are too succinct, devoid of discussion or evidence and come across as mere lists of descriptions by comparison. However they are slightly better precisely where Willis and Clark break down which is in the coverage of eighteenth and early nineteenth century work. Even in the Commission volumes Victorian architecture gets slight coverage presumably because the writers of the Royal Commission were not overly enthusiastic about Victorian architecture which was yet to come back into fashion. The Pevnser entries meanwhile are shorter still but somehow manage to cover more ground and provide better summaries. What is missing from them, of course, is the quoting of primary materials and the depth of discussion of sources found in Willis and Clark. Of course it is definitely true that far more archival sources have come to light since they wrote, throwing new light on many of the buildings mentioned. However Willis and Clark did a remarkable job digging out relevant documents and much of their text has stood the test of time. So, for instance, despite a number of drawings having appeared for Trinity College Library, their account holds up today.

One thing that Willis and Clark's book shares with Pevsner and the Royal Commission books is a paucity of material on building services and construction. The supply of water and later gas are not mentioned anywhere, though admittedly service provision in the early nineteenth century in most colleges had changed little since they were first built. However gas must have been becoming more popular and water closets certainly started to appear in the later part of the century, albeit usefully confined to a block in the corner of the court. The singular lack of reference to any of the hidden parts of buildings that make them work is indicative of the general interests of most architectural historians and certainly not something confined to Willis or Clark. Architectural history still tends to concentrate on the pieces built for show and care less about how they were achieved or maintained behind the scenes: it concentrates on the what rather than the how. Yet it absence in the *Architectural History* is perhaps particularly surprising as Willis can be regarded as a pioneer of close analysis of structure.

It is however remarkable that here we are in 2016 talking about a book produced in 1886, exactly 130 years ago, that still remains the first port of call and starting place in any research into Cambridge architecture. It is, of course, useless for buildings built after 1886, which is the vast majority of the buildings that make up the University today. Perhaps that is why it remains unsurpassed. Today the University is so much larger, the faculties occupy hundreds of buildings spread over such a very wide area that it would be a monumental task to describe them all. In Willis's day you could walk between the two most widely spaced buildings in the University: Jesus and Peterhouse, in 15 minutes (Searby, 1997, 1). The modern equivalent, North West Cambridge to the New Addenbrookes site, would, according to Google Maps, take you 1 hour 40 minutes. Was it the case that Willis and his nephew embarked on the project at the last time it was feasible, before the huge expansion the University? If you were to embark on such a project today it is interesting to ponder how you would go about it and what the result might be given the much greater scale of the task. Perhaps someone will but in the meantime we should thank Willis and Clark for their *Architectural History of the University of Cambridge* which, despite its flaws, will I suspect will remain the standard work for some time to come.

Reference list

Bradley, Simon and Nikolaus Pevsner. 2014. *The Buildings of England: Cambridgeshire.* London and New Haven: Yale.

Brooke, Christopher. 1985. *A History of Gonville and Caius College.* Woodbridge: Boydell, 1985.

Brooke, Christopher, Roger Hughfield and Wim Swaan. 1988. *Oxford and Cambridge.* Cambridge: Cambridge University Press.

Buchanan, Alexandrina. 2012. Building a Monument: Willis, Clark and "The Architectural History of the University of Cambridge," *Architectural History* 55: 145–172.

Buchanan, Alexandrina. 2013. *Robert Willis (1800–1875) and the Foundation of Architectural History*. Woodbridge: Boydell and Cambridge University Library.

Cambridge University Website 2016a. "Publications: Facts and Figures" Last accessed 29 July 2016. http://www.admin.cam.ac.uk/offices/planning/information/statistics /facts/poster2016.pdf.

Cambridge University Website 2016b. "Student Statistics 2015–2016" Lasted accessed 29 July 2016 http://www.admin.cam.ac.uk/offices/planning/sso/studentnumbers/ 201516statistics.pdf

Clark, J.W. 1900. Robert Willis (1800–1875). In *Dictionary of National Biography*. Oxford: Oxford University Press.

Cooper, Charles Henry. [1860] 2012. *Memorials of Cambridge*. Metcalfe: Cambridge.

Cunningham, Colin and Prudence Waterhouse. 1992. *Alfred Waterhouse 1830–1905*. Oxford: Clarendon Press.

Frijhoff, Willem. 1996. Patterns In Walter Rüegg, *A History of the University in Europe*. vol.2, pp.43–110. Cambridge: Cambridge University Press.

Higher Education Statistics Website 2016. Last accessed 29 July 2016. https://www.hesa.ac.uk/stats

Leedham-Green, Elisabeth. 1996. *A Concise history of the University of Cambridge*. Cambridge: Cambridge University Press.

Marsden, Ben. 2004. Willis, Robert (1800–1875) In *Oxford Dictionary of National Biography*, ed. H. C. G. Matthew and Brian Harrison (Oxford: OUP, 2004); online ed., ed. David Cannadine, October 2009, http://www.oxforddnb.com/view/article/29584 (accessed August 4, 2016).

Roach, J P C. 1959. *A History of the County of Cambridge and the Isle of Ely: Volume 3, the City and University of Cambridge*, London: Victoria County Histories. Available online at *British History Online* http://www.british-history.ac.uk/vch/cambs/vol3 [accessed 24 July 2016].

Royal Commission in the Historical Monuments of England [RCHME]. 1959. *An Inventory of the Historical Monuments in the City of Cambridge*. London: HMSO.

Sterland, E.G. 1951. The Early History of the Teaching of Engineering in Cambridge, *Transactions of the Newcomen Society* 28: 263–275.

Watkin, David. 1988. Introduction In Robert Willis and John Willis Clark *The Architectural History of the University of Cambridge* . Cambridge: Cambridge University Press.

Willis, Robert and John Willis Clark [Willis and Clark]. [1886] 1988. *The Architectural History of the University of Cambridge* . Cambridge: Cambridge University Press.

Robert Willis's Networks of Knowledge

Alexandrina Buchanan

A key aim of the Symposium 'Robert Willis: Science, Technology and Architecture' was to bring together modern experts in the many different fields to which Willis had made a contribution, both to explore the breadth of his interests and to gain new perspectives on what might have connected his different endeavours. We also wanted to identify the international dimensions of his work: how his ideas influenced and were influenced by those emanating from other countries and identify any links with scholars abroad. Talk of connections and links presents knowledge itself as a network —not simply discrete and isolated ideas and information, techniques and methods, inferences and explanations, but ones which might be shared across different fields and disciplines. In its creation, dissemination and maintenance, knowledge also depends on networks of people— researchers, publishers, educators and readers —who use their relationships for knowledge acquisition, testing and communication. Although none of these proposals is new, the possibilities for identifying and analysing such networks have been significantly improved by digitisation, both in the form of digital materials by which connections may be more easily located and softwares for visualising and interrogating the connections found. This essay will employ a mixture of digital and traditional methods to explore the human networks with which Willis can be associated, in order to try to understand the nature of his participation and as context for his contributions and influence to be discussed by other authors. This has value not merely for reaching a better understanding of Willis as an individual, for as this symposium demonstrates, Willis's polymathic range made him a potential bridge between different fields, at a time when it was still possi-

ble to believe that all forms of knowledge were inter-related and mutually supportive but when, in practice, disciplinary and professional specialisation was reducing the capacity for any individual to participate equally in all fields and the findings of science were increasingly challenging orthodoxies, those of religion in particular. Focussing on one individual also helps to explore both the potential and the challenges of network analysis in a historical context. As networks may seem to have replaced on the one hand individual genius and on the other class and economics as explanatory models, an individual focus can also remind us of the limitations and contingency of networks for historical explanation.

Networks

Relational sociology, the field from which social network analysis proceeds, emphasises the importance of social networks to all human endeavours, including movements, scenes and worlds; nevertheless, the nature of such networks is historically specific. It has been argued that from the late eighteenth-century, as towns expanded and population mobility increased, associational activity started to replace the extended family, neighbours and the Church as structures of support and sociability (Clark 2000). As Paul Elliott puts it, "Collectivism combated the social fragmentation, social mistrust, alienation and isolating tendencies of urban life" (Elliott 2003, 365). These local associations with a broadly Enlightenment remit were supplemented in the nineteenth century by increasing numbers of bodies, both national and local, which were both more narrowly specialist (special interest societies and professional bodies) and more specifically sociable (gentlemen's clubs).

The significance of networks to Willis and his peers has already been identified, with widespread discussion of the so-called 'Cambridge Network', the grouping of scientists associated first with the Cambridge Analytical Society founded by Charles Babbage, then with the Cambridge Philosophical Society founded by William Farish and others, and which eventually came to dominate both the British Association for the Advancement of Science and most of the nation's public positions in science. Other contemporary networks with which he has been associated include the Cambridge Camden, later Ecclesiological Society, and the Archaeological Institute. All of these can be identified as networks of knowledge —their objective was to create and shape particular forms of scholarly endeavour for public benefit. As Lubenow has observed, in the nineteenth century, learned societies, rather than universities were the key sites for intellectual innovation (Lubenow 2015, 27).

There is nevertheless a vast gap between recognising the necessity of networks and being able to reconstruct them in their historical specificity, and a fur-

ther gap between knowing what networks existed and understanding how any individual within the network used its links for personal advantage. Nineteenth-century networks have previously been studied anecdotally in terms of the social connections —the ties of friendship or cooperation between their members, or administratively— the formal associations by which informal connections were made public and institutionalised, or prosopographically —through genealogical links or exogenous characteristics of the groups, including the gender, educational background, religious and political affiliations of the members. It is also necessary to recognise that although humans are social beings, networks— particularly formal associations —take effort to set up and maintain, which normally falls to key individuals. Ties within networks are constructed, managed and maintained by means of the cultural work involved in discursive practice (McLean 2007, xi). Others participate to a greater or lesser degree and the extent or nature of participation— whether competitive, combative or cooperative —may not directly correlate to the extent of their social, cultural or intellectual capital. "It is not just networks or memberships that matter, but also how these relationships are represented, activated or suppressed in social settings" (Mische 2003, 258). Undertaking systematic study of how individuals made, used and were used by their networks helps us to understand the social webs through which economic, social, cultural and intellectual power could flow, by whom it was brokered and how it might have been impeded.

Societies

In discussing Willis's networking activity, the first aspect to consider is his participation in formal associations, the clubs and societies so essential to nineteenth-century knowledge construction and dissemination. Willis was not a serial joiner of societies and the list of those to which he belonged is as notable for the absences as for the inclusions. He never became a Fellow of the Society of Antiquaries, nor did he join any local antiquarian societies, other than the Cambridge Antiquarian Society, of which he was a founder. He served on committees of the Royal Society of Arts but did not become a Fellow. Despite an interest in language he did not join the Philological Society, set up by Edwin Guest (fellow Caian and member of the Archaeological Institute), of which his friends William Whewell and Albert Way were founder members. Nor was he a Freemason. The list of bodies to which he is currently known to have retained a long-term association is as follows: the Archaeological Institute (A.I., formerly the British Archaeological Association, B.A.A.); the Athenaeum; the British Association for the Advancement of Science (B.A.A.S.); the Cambridge Antiquarian Society; the Cambridge Philosophical Society; the Geological Society; the Institution of Civil

Engineers; the Honourable Society of Gray's Inn; the Royal Society and the Royal Institute of British Architects. All of these are specifically learned or professional rather than primarily social bodies. At the time of his joining, membership of the Athenaeum was a marker of intellectual distinction: the Marquis of Northampton (member of the B.A.A.S. and later President of the Royal Society and the A.I.) was one of the five trustees and fellow members included many of his circle of friends and collaborators, including Charles Barry, George Basevi, C. R. Cockerell, George Peacock, Albert Way, William Whewell and most of his contacts within the Royal Society.

The digitisation of the Royal Society's Fellows' nomination papers offers the opportunity for further investigation of the nature of Willis's involvement in that body. Willis became a Fellow in April 1830, the year of the controversial election of the Duke of Sussex as President (Hall 1984, 57–62). Fig. 1 is a visualisation of the members whose nomination papers Willis signed, along with their other signatories – which tells us little other than that the network was large.

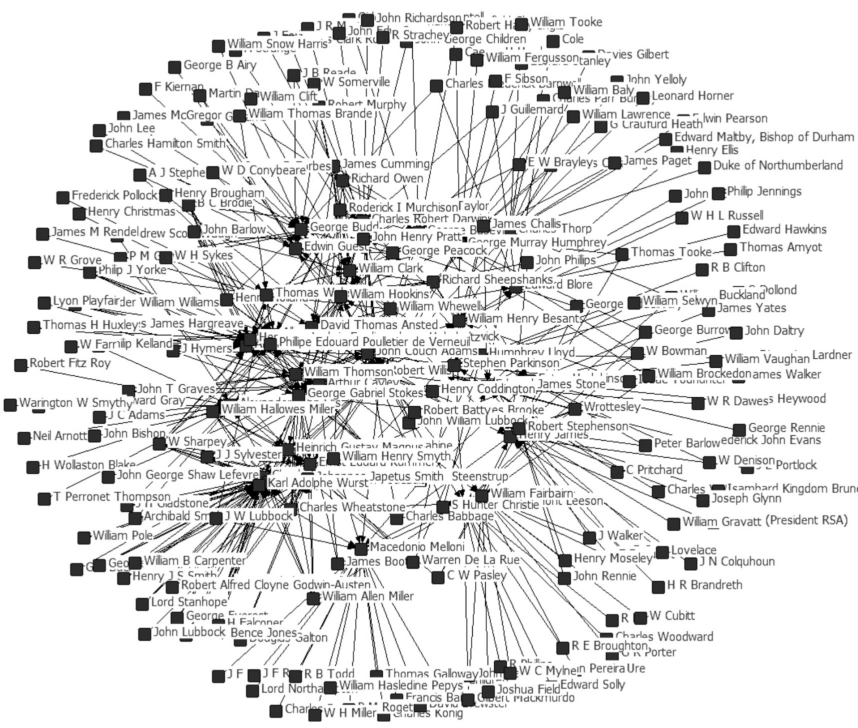


Figure 1
Visualization of signatories of Fellows' Nomination Papers signed by Willis

Reducing the numbers to look just at those he nominated and those who nominated him (Fig. 2), some patterns begin to emerge: the majority were from Cambridge, with a disproportionately high number from Caius, his original college, although still outnumbered by Trinity. Most were academic, with physics being the dominant specialism, although his other interests in engineering, architecture and philology are apparent. Although himself a scientist, his support for Blore and Basevi may suggest Willis was less purist in his attitude to Royal Society membership than Babbage, who campaigned for the election of John Herschel as President rather than the royal duke. Willis's signatures for his architectural friends predate 1847, when the election processes were reformed in order to make the Society more rigorously selective (Geike 1917, 348–9; Hall 1984, 78–82). The later nominations are predominantly foreign but analysis of international membership overall shows no rise during this period, so Willis's nominations

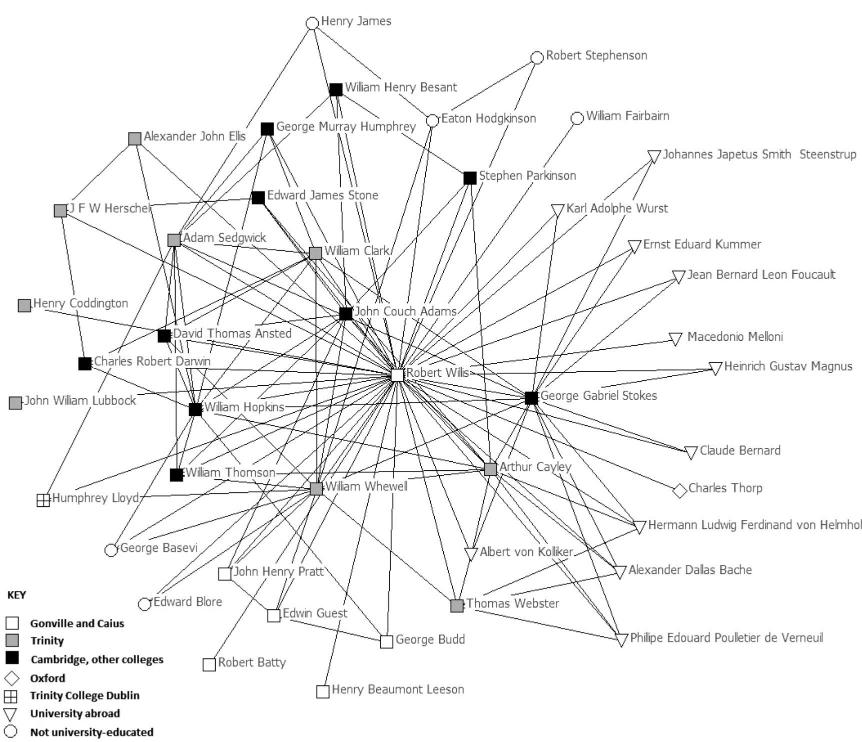


Figure 2
Visualization of those who signed Willis's papers and those whose papers he signed, showing place of education

are not part of campaign to recruit foreign scientists, merely business as usual for a council member. Unsurprisingly, a similar pattern emerges when we explore the names appearing alongside Willis's on the papers he signed. There is no evidence that Willis used his role as a possible intermediary between the worlds of academia and practical engineering to sign up more practising engineers to the Royal Society.

Another way in which we can analyse this data is by looking at whose names are adjacent to Willis's in the list, based on the fact that nomination papers had to be physically passed from one signatory to the next and therefore that proximity on the paper represents proximity in reality (Fig. 3). This approach is more problematic because the papers include two lists of signatures: those who claimed personal knowledge of the candidate and those who knew him only by reputation and there is no reason to suppose that signatories could not pass to someone in

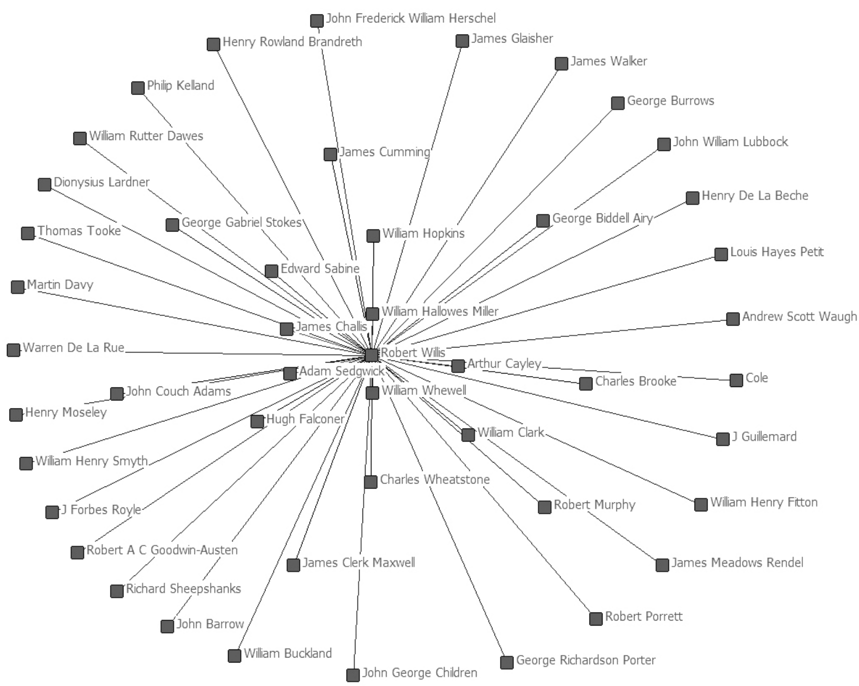


Figure 3
Visualization of adjacency data from Royal Society Nomination Papers. Proximity to Willis indicates number of times the named individual appears before or after Willis in the list of nominations (closer = higher number). Names not appearing next to Willis's have been removed

the other category rather than to the next name in their own list. However counting the number of times names are adjacent to each other adds weight to this evidence and although it should be treated with caution, some interesting findings emerge. Firstly, the visualisation suggests that the most significant figure in Willis's network was William Whewell. If we exclude W. H. Miller, with whom Willis served on the Council and where his name appears with exactly the same other signatories, all also council members, Whewell either passed papers to Willis or received them from him nearly twice as many times as the next most significant figure, Adam Sedgwick, whom we also know was a friend as well as a colleague. The importance of Whewell corresponds to the intellectual significance to Willis he has been accorded by Pevsner, Marsden and myself (Pevsner 1972; Marsden 2004; Buchanan 2013). Unsurprisingly, his brothers in law James Cumming and William Clark also recur in this adjacency data —perhaps more surprising is the number of times Willis and Charles Wheatstone exchanged papers. Although the two men addressed similar research questions in the 1820s, this is rare evidence of personal contact. Further investigation has identified that all these transactions took place when the two men were serving together on committees, both for the Royal Society and the British Association for the Advancement of Science.

In total, Willis signed the papers of forty five Fellows, although the only nomination he initiated was that of George Gabriel Stokes, with whom he collaborated on the Royal Commission on the Use of Iron in Railway Structures. This number may be compared with totals of eighty five from Babbage, seventy six from Whewell and one hundred and eleven from Charles Wheatstone. Whilst significantly higher than the election nominations by those more distanced from the Royal Society either by geography or specialisation (such as Edward Blore or William Fairbairn), these numbers suggest Willis was not a particularly active recruiter even to a body he may be assumed to have supported. Nor was he ever a member of the Royal Society Club, its dining club.

We should read too much in to what I am suggesting is restricted participation in associational activity, for others made less effort than he. For example, although older than Willis, his brother-in-law William Clark was later to join the Royal Society and neither he nor Willis's other brother-in-law James Cumming appears on the 1840 membership list of the Athenaeum. Although Whewell was elected to membership of the Royal Society's Dining Club in 1840, four years later he was deselected for non-attendance (Geike 1917, 329, 340, 348). It is also clear that Willis was prepared to play an active role in those associations to which he belonged: he served as President of the Architectural Section of the B.A.A. in 1844 and of the A.I. in 1846; of the Cambridge Antiquarian Society 1850–52; of the Cambridge Philosophical Society 1849 (as well as serving as one of the three secretaries 1836–

50); of the B.A.A.S. when it met in Cambridge in 1862 and of its Mechanical Science committee (Committee G) in 1839 and 1842. Further research needs to be done to assess the overlaps of membership between the bodies in which Willis was active and the characteristics of members, but letters suggest that he could at times be a bridge between them: when the A.I. met in Winchester in 1845, Willis had persuaded Whewell to act as President of the Architectural Section and friendship between the two men suggests he may have put forward George Peacock as President at Norwich in 1847. Both men were primarily known as scientists but their intellectual (and in Peacock's case, ecclesiastical) status would have made them valuable additions to the A.I.'s proceedings.

Man of Letters

Societies provided a formal mechanism for networking, which often overlapped with more personal networks: friendships in particular could be established and cemented through shared participation in associational activity. However the scale of congresses such as the B.A.A.S. or the A.I., which regularly attracted several hundred participants mean that further evidence is required to identify direct contacts.

One way in which scholars have identified and explored personal networks, or 'ego-nets' is through correspondence (Edwards and Crossley 2009). Epistolatory networks have long been used to understand biography in a wider context: Willis's nephew, J. W. Clark, was active in saving and publishing the letters of Willis's friend, Adam Sedgwick, and several other members of the so-called Cambridge Network had contemporary or near-contemporary biographies or autobiographies published which consisted primarily of letters (e.g. Sharp, Tait and Adams-Reilly 1873; Todhunter 1876; Stair Douglas 1881; Clark and Hughes 1890; Airy 1896). There has subsequently been a long-running project to calendar the correspondence of William Whewell, whilst the Darwin Correspondence Project has brought such endeavours into the digital environment (https://www.darwinproject.ac.uk). Since 2009, the 'Cultures of Knowledge: Networking the Republic of Letters, 1550–1750' project has developed the 'Early Modern Letters Online' database (http://emlo.bodleian.ox.ac.uk) and since 2011, the 'Victorian Lives and Letters Project' has focused on the possibilities offered by the digital environment to represent the Victorian past as "an interconnected web of personal letters, diaries, journals, and notebooks" which will 'highlight the complex interaction between private lives and public personas in Victorian society' (http://tundra.csd.sc.edu/vllc/).

Letters and journals offer a hugely valuable resource for historians, particularly in a period when the penny post made letter-writing more accessible, its efficiency

enabled near daily interactions via post and the lack of alternatives made letters a vital means of communicating with those too distant for face-to-face conversation. It is not to devalue their potential to nevertheless urge caution, lest history be written not from the point of view of the victors but from the point of view of those whose correspondents preferred to file than to dispose of their letters. It may prioritise the perspective, or interests, of those distanced from central events (two people at the heart of things would not need to have communicated via letter) and could marginalise those whose letters do not survive (or never existed). The nature of correspondence disrupts the apparent logic of the archive —that the archive holds the papers of that archive's creator— and demonstrates that an archive is created not through authorship but through the act of consignation. An individual's archive includes those letters received from others and kept, but the letters authored by the individual will only be in that individual's archive if they remain unsent (and therefore do not perform the basic function of a letter to communicate). It is only through the creation of virtual archives that the letters sent and those received can be united to create the simulacrum of a conversation —but in most cases only one side of the conversation survives.

Letters support the significance we have attributed to associational activity and throw further light on the internal dimension of associational behaviour. In several of Willis's letters we find reference to common acquaintances, for example a letter to Babbage of 1849 that mentions Manchester contacts "our friends the Kennedys – Fairbairn – Nasmith – Whitworth – at least I believe you know them as well as I do. If not I shall be most happy to introduce you" (British Library, Add MS 37192, f.475). Equally prominent in Willis's correspondence, however, are efforts to dissociate himself from groups to which he did not want to belong. In a letter to James Orchard Halliwell, founder of the Historical Society of Sciences, Willis asked that his name be removed from the list of Council members "as I find it impossible to work for you and greatly dislike mere sinecure positions" (Edinburgh University Library, L.O.A. 16/49) whilst in a letter to Dawson Turner he wrote:

> I received from you some time since a book which in accordance with your request I have forwarded to the [Cambridge] Camden Society. I ought to mention at the same time that I have withdrawn my name from that Society long since, in disgust at the tone which they have thought proper to assume in their publications, all of which are anonymous & for the most part written by men of no standing in the University. (Trinity College Library, O.14.32, no. 103).

Such comments support the earlier suggestion that he was a discriminating participant. The sense of limited involvement, fraternisation on his own terms, is

also a feature of his correspondence as a whole. This is important, because even in this period of epistolatory overload, Willis's correspondence suggests that there were significant figures who may not have fully participated. Just as figures who today do not engage with social media may be rendered less visible in public discourse, so yesterday's reluctant correspondents may be rendered disproportionately less significant. There is also the equally troubling problem of archival absence. The first issue is the non-survival —or non-accessibility— of whole fonds, that is to say the archive of a single individual. To give an idea of the extent of the problem, let us return to Willis's ego-net as represented by the Royal Society nomination papers. Fig. 4 highlights those members of his network whose archives survive. Among these surviving *fonds*, only four hold any Willis correspondence.

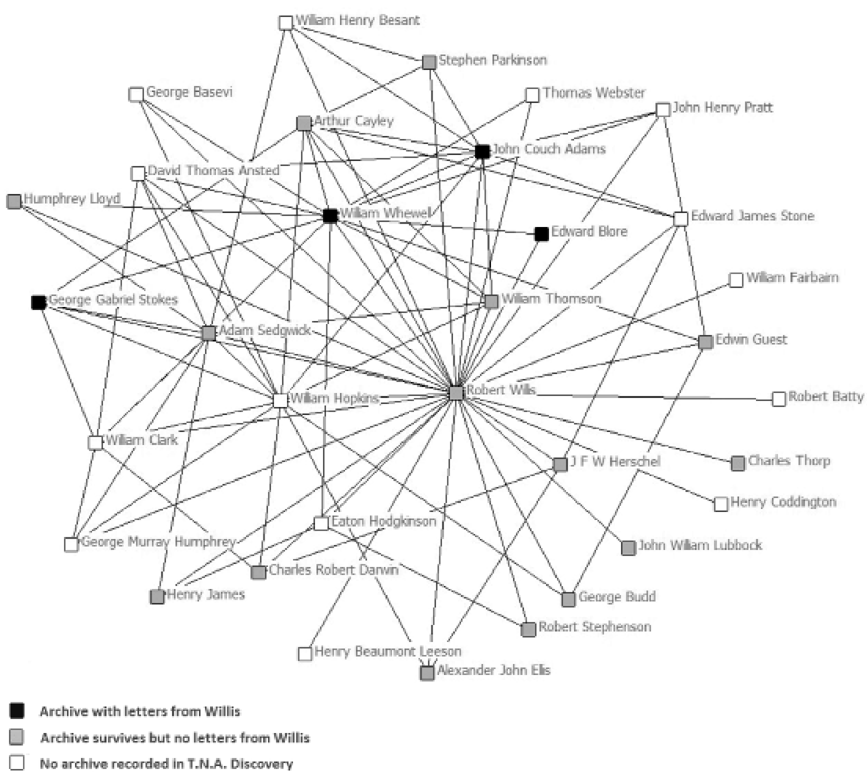


Figure 4
Visualization of those who signed Willis's papers and those whose papers he signed showing archival survival

We also need to account for the processes of appraisal and destruction which have shaped even the archives which survive. As an example, knowledge of Willis's career makes it obvious that he must have corresponded with E. A. Freeman, the historian who wrote the only obituary of Willis not penned by Willis's nephew. There is no evidence that the two men were close but Freeman succeeded in persuading Willis to lecture on Wells Cathedral to the Somerset Archaeological and Natural History Society, the only known occasion when Willis condescended to speak to any such group other than the Cambridge Antiquarian Society which he had helped to found. This must have involved an exchange of letters but although Freeman's admiration for Willis was enormous, he did not preserve their correspondence. Thus the Freeman archive preserved in the John Rylands Library, which includes 1625 letters, contains not a single epistle from Willis and there are no letters from Freeman in the Willis archive in Cambridge.[1] Other surviving archives have equally paltry remains: besides the three letters mentioned above, Charles Babbage's archive has only four letters from Willis and Darwin's has none. In the antiquarian sphere, Dawson Turner's archive has only one letter from Willis whilst the huge Nichols family archive has none. The largest cache so far found is in the archive of Charles Henry Hartshorne, a Cambridge contemporary and fellow bibliophile, who is mentioned in Romilly's diary as undertaking an "Architectural tour" with Willis (Bury and Pickles 1994, 61). Their correspondence includes just nine letters, spread over two decades, plus an additional 'stray' in a Wellcome Library collection of miscellanea (MS 8007/32/4). The reason for such limited survival is impossible to state with certainty, but examination of those letters that survive may offer some clues.

That Willis was not a prolific correspondent is suggested by a letter in his own archive, from John Stacye, curate of Worksop in Nottinghamshire asking for advice on restoration work being undertaken at his church. Stacey notes that he had written previously but had not received any response (CUL MS Add. 5141, item 8). He also apologised to Hartshorne "as usual" for not having answered his letter "with due promptitude." (Northamptonshire Record Office, HaC III E 609). In Whewell's archive are two letters using Whewell as a broker to gain access to information from Willis: in 1843, Richard Jones, the economist, wrote to Whewell about the productive power of the nation: "why do I scribble all this why I want to ask you if you think Willis would give any thought to the subject if I wrote a short paper on it and sent it to him" (Trinity College Cambridge, MS Add. C 52 78). Whether he did so is unknown, as Jones's own archive does not survive and there are no letters from Jones in Willis's papers. Similarly, in 1845, Baron Lyttelton sent plans of a chapel he was erecting to Whewell asking for his opinion and that of Willis. This could perhaps point to Willis having an aloof reputation, which might have discouraged a more direct approach; it also sup-

ports the identification of the strong link between Willis and Whewell already mentioned.

It is unsurprising that those seeking to enlist Willis's support should abase themselves: an 1849 letter from Henry Bassett of Norwich which raised concerns about restoration work at the cathedral, opened with the statement that he "must plead my excuse in addressing this epistle to you; your thorough knowledge and superior judgment of the architecture of the middle ages, and your consequent influence in these matters, are well known", and concluded, "I beg of you to pardon the great presumption of so humble an individual as myself in thus intruding my remarks upon your notice" (Norfolk Record Office MC 186/369/14–16). Nevertheless, even peers seem to have emphasised his expertise and authority: writing on the same topic, the Dean of Norwich was anxious to have Willis's "authority and kind advice" as to whether there was any order in which the replacement statues of the apostles ordered to adorn the cathedral buttresses should correctly be placed. He added, "This I fear will appear to you a ridiculous question but I am so afraid of going wrong" (Norfolk Record Office, MC 186/369/22–24).

The letters which survive suggest Willis's own correspondence style was brief and to the point. Few extend beyond a single sheet and few contain personal detail beyond the informational. The most discursive so far found are those to Hartshorne, which show evidence of mutual friendship, concern for each other's families and a shared waspish sense of humour: writing of Watkins, the incumbent of Brixworth parish church (Northamptonshire), a Saxon structure which Watkins had identified as an early Christian basilica, Willis reported "I was glad to get him out of my house as civilly and rapidly as I could… Between us we made long & short work of our interview. He was long & I was short" (Northamptonshire Record Office, HaC E 616). Dean Pellew's fears with regard to the restoration of Norwich appear well-substantiated: Watkins's work at Brixworth is described by Willis as "medling & pedling schemes", and in relation to the proposed restoration of the round church at Northampton, he wrote, "I am utterly disgusted with the wholesale sacrifice of relics of antiquity which is going on all round us under the pretence of preserving & restoring them" (Northamptonshire Record Office, HaC E 616; HaC E 615). Several letters also attest to Willis's busy-ness, his perception (whether justified or not) that he was over-committed and could not take on further responsibilities (Northamptonshire Record Office, HaC E 615; HaC III E 616; Wellcome Library, MS 8007/32/3).

Finally, we have evidence that Willis was secretive and disinclined to share his research prior to public announcement via lecture or publication. In an 1841 letter to Hartshorne, he writes of a book he had ordered from Bohn's catalogue which had turned out to be even more valuable than expected but "what that is and why so to me inestimable is too mysterious a matter to trust to paper but I

will whisper it in your ear when you come to Cambridge." (Northamptonshire Record Office, HaC III E 608). Another of his closest collaborators was David James Stewart, Canon of Ely, with whom he worked at that cathedral and who collected architectural evidence for him. In 1852, Willis asked Stewart for information about continuous masonry coursing in Early English masonry versus discontinuous courses in Decorated work, which he considered to be a new discovery. Tellingly he added: "& keep the secret to yourself" (Cambridge University Library, MS EDC 14/37/2). This suggests that, in contrast to many of his peers, for whom scholarship was a collaborative project, with letters serving as a means of sharing data, discussing methods and results, and building a research community, Willis was a loner, who shared his ideas with few and reached conclusions on his own. If so, we might conclude that even those to whom Willis may have written might not have bothered to save his letters because their content was limited, with little long-term value.

The survival of letters in Willis's own archive is both patchy and unsystematic, so cannot be used to construct a comprehensive picture of his personal network. It has a total of sixty one correspondents, including names which might otherwise have been unidentified as contacts, such as Joseph Burtt of the Public Record Office. Nevertheless, it does offer some interesting clues to his personal relationships. Without the letters, it might not have been possible to identify what were evidently three significant collaborations: with D. J. Stewart, Arthur Rigg of Chester, and his brother-in-law, Charles Humfrey. In all these cases a similar form of relationship emerges: although in each case participating in a shared project (data collection, educational model-making and patenting a letter-balance respectively), Stewart, Rigg and Humfrey present themselves as subordinate to Willis through flattering, offering assistance or seeking approval. This corresponds with what we know of Willis from other sources: for example, in 1848, Charles Cardale Babington, a fellow founder of the Cambridge Antiquarian Society, made an excursion with the Rev. John James Smith, Augustus Wollaston Franks, Frederick Townsend and Lukis (unidentified member of the Lukis family of Guernsey, possibly William Collings Lukis) to Bottisham (Cambridgeshire) where they "spent some hours in the careful examination of the church, under Willis's direction" (Babington 1897, 147). Although Smith and Babington were near contemporaries of Willis, and Babington had dined with him several times, the relationship is clearly presented as asymmetrical. Thus Willis's letters seem to corroborate the view, gained from looking at his associational activity, that his participation was limited and very much on his terms. Let us now turn to look at how he managed the relationships in which he had less choice —his family ties— and consider what these can tell us about how the cultural capital acquired through social networking could be passed on.

Family

Although voluntary associations have been identified as particularly significant to nineteenth-century knowledge creation, genealogical ties have also been linked to intellectual networks. Perhaps the most-cited article on social network analysis *avant la lettre* is Noel Annan's 'The Intellectual Aristocracy' of 1955, which used the ties of blood or marriage to present a picture of a close-knit elite encompassing many of the individuals Willis would have known (Annan 1999). The nature of that elite is not defined, simply presented as self-evident through enumeration of the positions held (with an emphasis on Oxbridge status, literary production and public service). Nevertheless its gentrified character is implied through the fox-hunting metaphor which holds the argument together. That readers were evidently expected to understand and accept such a metaphor anticipates their shared membership of this elite —and consequent disinclination to challenge its existence. Yet its evidential basis is undeniably weak— rather than starting by defining the elite and then assessing the characteristics of its members, including their ties of kinship, a network is constructed which is then taken as the elite in its totality.

William Whyte and William C. Lubenow have offered a definition which looks to a shared culture, rather than common genealogy, but retains the focus on those who were indubitably part of the elite as (un)defined by Annan and connects its emergence with Oxbridge reform (Whyte 2005; Lubenow 2010 and 2015). Willis himself died too early to play a personal role in the world they describe (despite the date range, Lubenow's focus is on the latter part of the nineteenth century) but the choices he provided for his children helped to establish the terms of their involvement (or not). Willis's descendants shared the same blood and all could access the same culture, although the extent to which they participated is unrecorded but, as will be shown, Oxbridge attendance, so important to Annan, Whyte and Lubenow, was limited. Willis's family were not 'philistines', nor were they excluded from the intellectual aristocracy through class or religion. Which of them should be included, however, is a question on which the definition of the intelligentsia depends and much else besides, for many arguments about Britain's industrial 'decline' have focused on existence, or not, of an anti-industrial or anti-entrepreneurial bias in British culture (Wiener [1981] 2004; Dintenfass 1992; Edgerton 1996). Such bias is evident in Annan's account, where it may be noted that many of his examples are defined as 'Quakers' rather than 'businessmen', even when the latter label would have fitted equally well, but we should take care not to project this backwards onto career choices made in the nineteenth century. The story of Willis's kinship network therefore provides a case study of how boundaries

have been constructed between intellectuals and technological elites, as much by historians as by contemporaries.

If we accept the existence of an intellectual aristocracy in the second half of the nineteenth century, Willis was undoubtedly a member, though his introduction into the caste originally depended less on intellect than on the eighteenth-century system of privilege and placement. His grandfather's treatment of George III enabled him to secure sinecures for all but one of his sons, who had a disability —but only three of them had offspring (Fig. 5). All the grandsons went to Oxbridge, after which two went into medicine, Willis pursued an academic career and the rest went into the Church. There is no evidence that Willis maintained contact with any of his cousins and further probing may help to suggest why. The three boys closest to his age were clergymen, but the Rev. John Willis (1799–1855, son of Thomas) seems to have been married to an alcoholic, ran into financial difficulties and was found guilty of being drunk in the pulpit and visiting a brothel, whilst the Rev. Richard Child Willis (1799–1877, son of Richard) was convicted of fraud, spent a year inside, then, whilst still married, cohabited with a woman less than half his age, whom he claimed was the widow of his non-existent son but who is described as his wife in the 1861 census, all this whilst his actual wife was living with her brother (Adams n.d.). The Rev. Thomas Willis (1801–1857, son of Thomas) who, unlike the others, studied at Cambridge, seems to have been more respectable so we know less about his activities, but nevertheless there is no evidence of any connection with his cousin Robert.

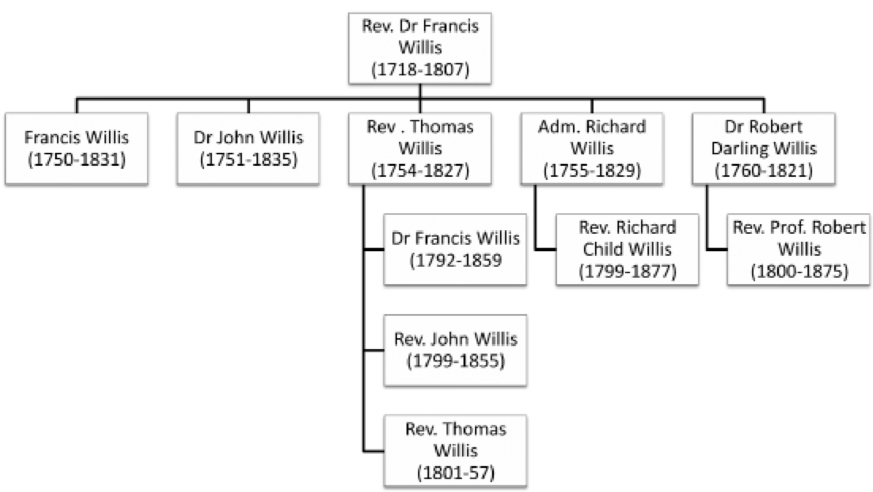


Figure 5
Sons and grandsons of the Rev. Dr Francis Willis

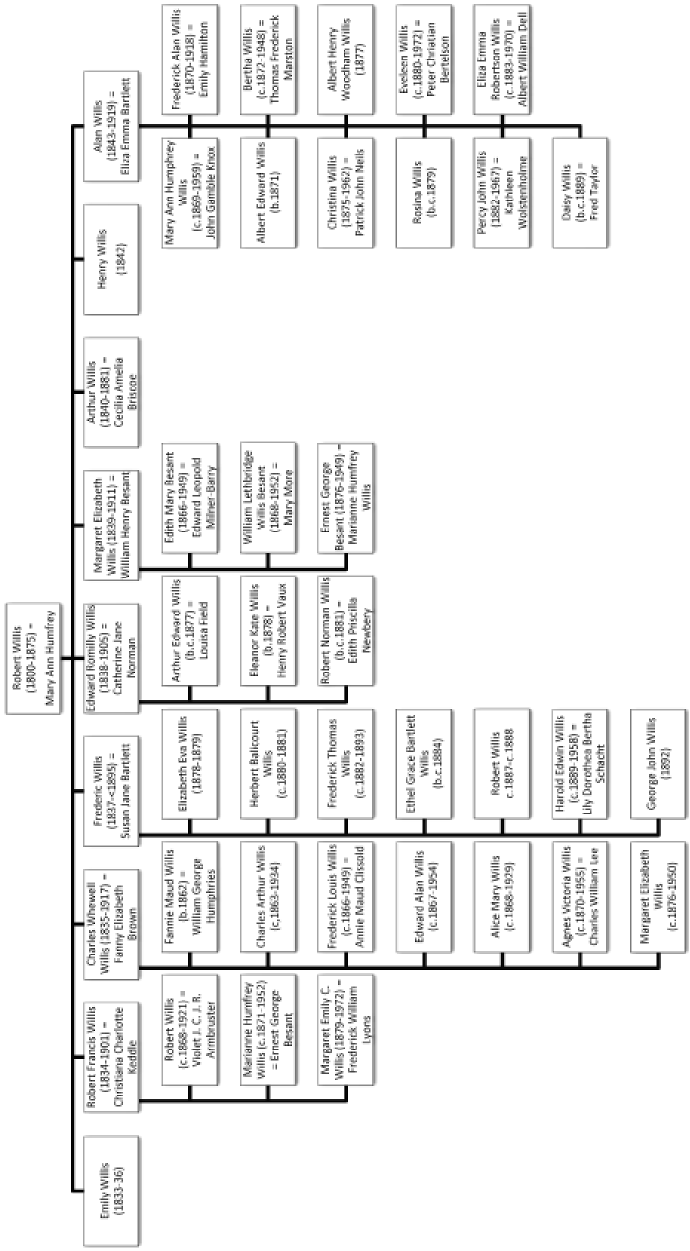


Figure 6
Children and grandchildren of Robert Willis

Willis's own descendants (Fig. 6) had their share of irregularities (at least two cohabited before marriage, according to their census returns) but the reason for their general exclusion from the intellectual aristocracy as represented by Annan seems to depend more on their educational than their ethical path. We do not know when or why Willis fell out with his eldest son, Robert Francis, who attended Cambridge but failed to shine and eventually entered the Church, where he had an equally undistinguished career. However his offspring fit the model of an intellectual elite: his son became a diplomat, his elder daughter married one of her Besant cousins and the daughter of his younger daughter (who was married in Cambridge by another of the Besants) became a respected Arthurian scholar.[2] Willis's only surviving daughter Margaret fits the pattern even more closely: she married Cambridge mathematics coach William Henry Besant and produced three children with impeccably Cantabrigian credentials, whose children in turn maintained their status.

By contrast, Willis's younger sons followed a very different educational trajectory. Aside from Frederic and Arthur, for whom Willis purchased a passage to New Zealand and a farm for when they arrived (Adams, n.d.), Charles, Edward and Alan all pursued their father's scientific pathway and none studied at Cambridge.[3] Charles became a mechanical engineer in London —he was a member of the Institute of Mechanical Engineers but was not accorded an obituary. He lived at various addresses in London, before dying as a man of independent means in Peckham. He had seven children but none of his sons is recorded as anything more than a clerk. Edward became a civil and mechanical engineer through pupillage with William Fairbairn and James Brunlees and worked both at the Landore Steel Works in Swansea and on the Sao Paolo Railway in Brazil (information from his election papers to the Institute of Civil Engineers). Willis probably set up this pupillage for he knew Fairbairn well. He became a member of the Institute of Civil Engineers but, again, did not merit an obituary. Of his three children, his sons are recorded on the 1911 census as sewing machine and typewriter salesmen. Finally, Arthur attended the Royal School of Mines and became an industrial chemist at the Landore Steel Works in Swansea. He was accorded an obituary in the *Journal of the Chemical Society* for his original research, but it was claimed that work commitments and ill-health prevented him from publishing much and he died young in 1881, married but without children.

Although we cannot draw wider conclusions from an individual family's history, it is notable that of Willis's descendants, only those who retained a Cambridge connection held the sorts of academic and public service roles which characterise both Annan's intellectual aristocracy and Lubenow's liberal intellectuals. The three engineers seem to have had adequate intellect, joined professional bodies and, especially Arthur, aspired to making a scholarly contribution, but their physical loca-

tions, choice of wives and the direction of their studies were not congenial to an insider status based on literary endeavour and metropolitan activity. In contrast to Lubenow, who includes 'liberal' professionals as part of his elite, T. W. Heyck identified the drive for professionalization as an anti-liberal principle (Heyck 1982, 107). We cannot answer the question of whether he could have been aware that by excluding his sons from Oxbridge, he was also excluding them from what otherwise might have been their birthright and, if so, whether his choice was a considered one. By all accounts a fond —indeed according to Romilly an over-fond— father (Bury and Pickles 2000, 265), it seems unlikely that he was deliberately alienating his offspring. Was he rejecting Cambridge and liberal values, or demonstrating preference for more vocational or professional training? As I have argued elsewhere, his own support for the Royal School of Mines suggests that he rated this institution highly and anticipated it would "turn out men of ability and acquirements equal in their own line to the great abstract philosophers of Cambridge & Oxford in theirs" (T.N.A., PRO 30/29/23/14). Perhaps he hoped his younger sons would attain "lucrative appointments from the government", which might have greater public benefit than his eldest son's role in the Church. With only circumstantial evidence for his motivation or theirs, we can but speculate —but their choice does not fit with a characterisation of a mid nineteenth-century intellectual culture as one which invariably devalued industrial science and practical expertise in favour of 'nobler callings' as has been suggested (Mayer [1981] 2010, 259).

If there is little evidence that Willis maintained connections with his father's family, there is more that he built relationships with his in-laws, the Humfreys. Here too the family's trajectory was away from Cambridge, breaking an existing link. The earliest evidence we have for a connection between the two families is in 1825, when Charles Humfrey, his future father-in-law, is named as a trustee of the fund established by Willis's father to support his children and their mother (T.N.A., C 13/368/25). It is possible that Humfrey may have known Willis senior from his time as a pupil of London architect James Wyatt, but it is more likely that his role derived from his status as a banker in Cambridge. Humfrey was a successful local businessmen —his father had been a carpenter, born in Norwich, whose father died young and who may have moved to Cambridge to benefit from family connections with the University (Fig. 7). These came via the descendants of his great uncle, Richard Humfrey, who seems to have taken responsibility for the widow and child of his brother. Richard Humfrey I was a wealthy worsted weaver with substantial property holdings in Norwich and in his will left his sister-in-law a number of properties in the Coslany district, as well as money to his nephew Charles and his two nieces (T.N.A., PROB 11/921/66). His will suggests he was a devout churchman and his son, Richard II, having studied at Corpus Christi College was ordained and served for many years as rector of Thorpe near

Norwich (Venn 1922–54). His son, Richard III, also studied at Corpus and was ordained (Venn 1922–54). He became tutor to the Royal Princes and was so esteemed by King George III that is said to have exclaimed "I can easily procure another tutor for the princes, but I shall never meet with another Humfrey". This Richard, however, predeceased his father in 1780. His brother, John, became rector of Wroxham, near Great Yarmouth, where he built himself a mansion —possibly designed by Humfrey— on the proceeds of three livings and an inheritance via his wife (Venn 1922–54). He was also a prebendary of Lincoln (providing another possible link with the Willises) but died without issue. His heir was one Robert Blake, who inherited the estate on the condition that he changed his name to Blake-Humfrey. The only connection I have so far been able to find between Blake and Humfrey is via Blake's wife, Charlotte, who was the youngest daughter of Lieutenant-Colonel John Harvey of Thorpe Lodge. The Thorpe link seems fairly tenuous, however, and it is interesting that a non-relative was prioritised over the Humfreys of Cambridge, although they did receive financial bequests (T.N.A. PROB 11/2062/137).

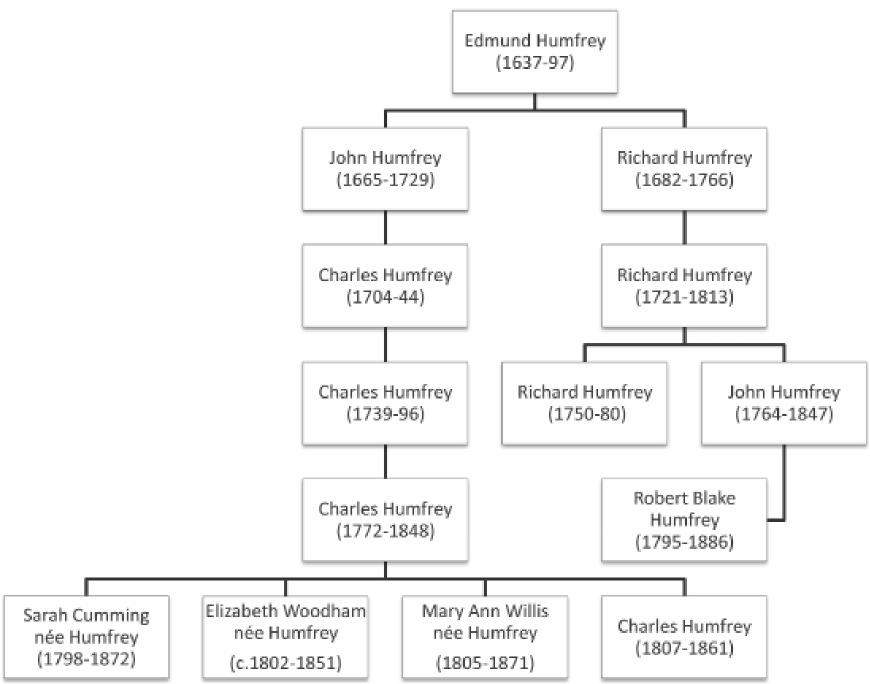


Figure 7
Humfrey family tree

Charles Humfrey could be portrayed as an architect on the make, but his family could boast a long landed lineage and their own heraldry. The careers of his children fit with this respectability. His only surviving son, Charles, attended Caius a few years after Willis and moved with him to Downing (Venn 1922–54), and all his daughters married dons. The eldest, Sarah, married James Cumming, Professor of Chemistry; the youngest, Mary Ann, married Willis, and the middle sister, Elizabeth, looked after her parents until their deaths, then married the much younger Henry Annesley Woodham, a Fellow of Jesus. Cumming, as the senior son-in-law, seems to have been the closest to Humfrey. He took a significant role in local politics and served as a magistrate. Like his father-in-law, he was strongly Whig. Cumming and Sarah had three surviving children, their son going into the Church. The elder daughter married a man of property and became interested in spiritualism (Myers 1903, 35–7), the younger married a clergyman with Cambridge connections. Chemistry became a significant strand linking the Humfrey siblings and their offspring —in older age, Mary Ann started her own chemistry experiments in pursuit of creating a purer soap, undertaken in a wash-house cum laboratory Willis had constructed for her in the garden of their house on Parker's Piece (Willis 1868, 1869 and 1871).

Cumming seems to have left no papers (Brock 2005, 141), so we have little evidence to work with but there are some clues that the Cumming and Willis families were close. Cumming officiated at their wedding in what had become the Willis family's London church, St Mary-le-Bone. The link between the two families probably also explains Willis's decision to move his sons from Marlborough College to King William's College on the Isle of Man, whose Vice-Principal from 1841, Joseph Cumming, was James Cumming's nephew and therefore the boys' second cousin.[4] Willis and his brother-in-law Charles Humfrey (Fig. 8) also seem to have maintained a close connection and it was Charles who travelled to Birmingham to try to put Willis's patent letter balance into production in 1840. Although after graduation, Charles nominally joined his father in the banking business, his interests were evidently more practical. In 1839 or 1840 he joined an oil, candle and soap manufactory in Hatcham, trading under the name E. Manning and Company. He lived in south London and on the 1851 census is listed as a candle manufacturer in Deptford. He died bankrupt in 1861, in which year his son Charles V is described as an oil refiner in Newington, South London, employing two hands. Both men appear as innovators, applying for patents for improvements to their processes (Museum of the Scottish Shale Oil Industry). One of them was a partner in the firm of Humfrey, Yooll & Co. who operated a refinery at Suffolk-grove, Southwark which processed imported Canadian crude oil. The works appear to have closed following outcry over the obnoxious fumes produced by the process. It was possibly after this closure that Charles V

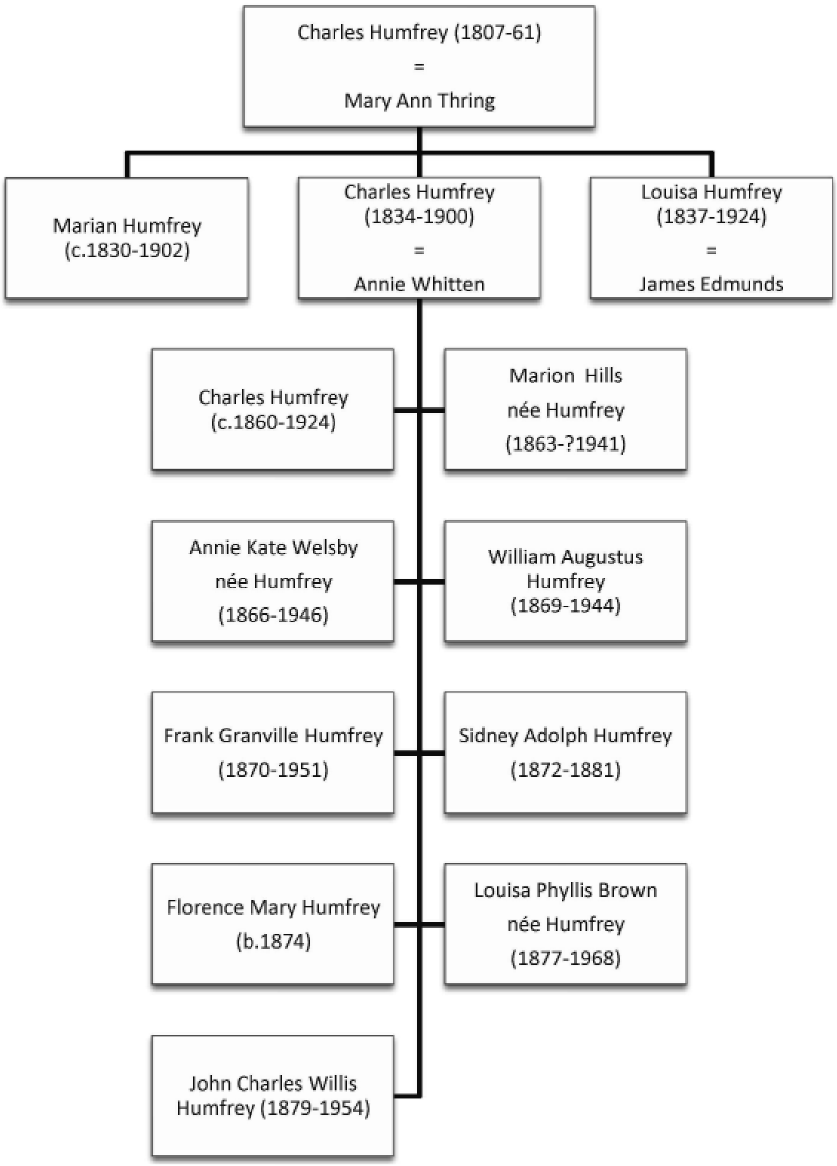


Figure 8
Family tree of Charles Humfrey, brother-in-law of Robert Willis

moved north to Cheshire, where he became a manager at the Saltney Oil works on the banks of the River Dee. There he was involved both in refining oil and extraction of shale gas. According to the 1881 Census he was his own boss in an oil manufacturing business employing 78 men, and from 1882–1890 he was manager of an alkali works at Northwich, Cheshire (Society of Chemical Industry membership lists). After his retirement he described himself as a manufacturing chemist, emphasising the scientific, rather than the mercantile nature of his career (1891 Census). He was a member of the Society of Chemical Industry, as was his eldest son Charles, who also managed alkali works in Cheshire.

Evidence for an ongoing connection with the Willis branch of the family is offered by Charles V's youngest son, who was named John Charles Willis Humfrey. He studied engineering at the University of Liverpool and then went on to study as an advanced student at St John's College, Cambridge. He became a metallurgist at the National Physical Laboratory, then worked as a metallurgist in the Admiralty Inspection Office during the First World War and went on to work for Sandberg's, an engineering company, where he invented the Willis-Sandberg freewheel clutch. He was awarded the O.B.E. in 1920 (Venn 1922–54). The link with Cambridge was evidently not automatic, suggesting that like the younger Willises, the Humfrey family had lost their Cambridge affiliation, through geographical distance and attachment to practical science —but having reconnected, J. C. W. Humfrey might be considered an intellectual aristocrat, with his public position and honour from the State.

Albeit limited, the example of Willis's family confirms the significance of the professions to nineteenth-century intellectual culture —for Willis, engineering seems to have held no inferior role to the Church as an occupation for his sons. Until the later nineteenth century, however, Oxbridge played little role in technical vocational education: to become engineers, Willis's sons had to eschew a University education, whilst half a century later, his great-nephew used it as an entry to a public position. Yet an academic education seems to have remained a key component in transmitting cultural capital and the occupational divide between those of the second generation with close Cambridge links and those without is readily apparent.

Conclusion

What can the patterns identified through studying Willis's networks tell us? Firstly, there is insufficient evidence to be able to use networks as a key to understanding his intellectual development, although the more systematic approach taken here seems to corroborate patterns already identified. Compared with the data available from citations within his publications, however, which attest to his

voracious reading, information about personal contacts is very limited. The poverty of data is partly the result of absence of evidence but there does also seem to be evidence of absence: that compared with some contemporaries, Willis was not heavily involved in networking activity and that had more letters survived, they might not have offered the richly personal, reflective and discursive resources found in other nineteenth-century correspondence. This is, of course, a risky statement which has to remain provisional.

Secondly, in terms of input, Willis belonged to more scientific bodies than he did antiquarian and architectural and these were more bureaucratic, with meetings of councils and committees in which Willis played an active role and which took up time. He was able to devote such time to the work because he had an independent income: the lower levels of participation by his brothers-in-law Cumming and Clark may relate to their parallel lives as Anglican clergymen. Nevertheless, Willis's correspondence suggests a level of over-commitment which may help to explain why many of his architectural papers remained unpublished.

Thirdly, from taking an overview of Willis's role within the networks with which he was involved, it seems apparent that he was only occasionally active as an interface between different parts of a network as a connector. That he had the potential to perform such a role is clear, particularly in engineering, where he had working relationships with both 'practical men' and academia, yet contributions deriving from this position seem relatively minor: offering a chapter to Barlow (1851), introducing William Hopkins to William Fairbairn, or encouraging Gabriel Stokes to teach at the Metropolitan School of Science. It is also only in science that he played a more ambassadorial or advocacy role: other than his keynote lecture, reports of A.I. Congress Proceedings reveal little input from Willis. The interests of his children and wife may also suggest that the topics most frequently discussed at home were scientific rather than architectural, for unlike the antiquarian dynasties spawned by Dawson Turner, Hartshorne and Albert Way, none of his direct descendants is known to have shared his antiquarian interests.

Finally, might the limited nature of his social participation in antiquarian networks help us to understand why his contribution, whilst demonstrably substantial, did not result in the establishment of architectural history as a formal discipline in Britain and why he had so few direct disciples? Most of the architectural historians working in early twentieth-century France trace a lineage back to Jules Quicherat or Viollet-le-Duc, yet none of those working in England at the same time had any personal connection with Willis. Whilst structural differences do play a part —Britain had fewer paid roles for architectural historians and therefore less support for their education than in France or Germany— but as I have suggested elsewhere, a more charismatic man, or one who was less of a loner than Willis, might have engineered opportunities to spread his influence. Such

circumstances were not impossible to achieve: at the Architectural Association, Edmund Sharpe's sketching club trained innumerable young architects in methods closely akin to Willis's and familiarised them with Willis's ideas. In the late 1840s, when he ran a series of lectures at the Royal Institution, paralleled at Cambridge, it might have appeared that Willis would establish both a popular and an academic programme of education in architectural history. But by 1850, his attention was called elsewhere —to the experiments on iron structures for the Royal Commission, to the Great Exhibition and subsequently to the Metropolitan School of Science and to his efforts to improve engineering education. Here too it might be argued that his unwillingness to enter into controversy and his lack of leadership were obstacles to achieving his aims— but more significantly, it led to a slowing down of architectural activity. By the 1860s, when his participation in the A.I. began to increase once again, he had become a 'grand old man' and perhaps the moment for new initiatives had passed. As he wrote in 1868 to an unknown correspondent who had apparently suggested he should undertake a study of Bath Abbey, "I can only repeat the old story, namely that I have my time completely filled up with the work of completing investigations voluntarily undertaken years ago & am compelled to decline new ones" (Wellcome Library, MS 8007/32/3).

Acknowledgements

I would like to thank the archivists of the repositories named below, as well as those of King's College London; the Honourable Society of Gray's Inn; Imperial College London; the Royal Institution, London; the Royal Society of Arts; Trinity College Dublin, and University College London for providing access to their holdings, answering enquiries, and providing copies of material. I would also like to thank Chris Adams for providing further information about the Willis family; Gerrylynn Roberts of the Open University for providing information from the Open University's Chemists' Database, and Elisa Bellotti, Martin Everett and Nick Crossley of the University of Manchester for providing training in the use of Ucinet, used for some of the visualisations.

Notes

1. Dade-Robinson 2015, 173 footnote 63 is incorrect.
2. The four children shown on the Willis Family Tree in Buchanan 2013 is incorrect: one of the daughters was known by two different names.
3. This information is a correction of Buchanan 2013, 223.
4. Not Cumming's cousin as previously identified: Buchanan 2013, 223, footnote 9.

Primary Sources

Bodleian Library: J.H. Parker Papers; Harcourt Papers.
British Library: Charles Babbage Correspondence
Cambridge University Library: Adam Sedgwick Papers; Edward Blore Papers; Ely Dean and Chapter Archive; George Gabriel Stokes Papers; Robert Willis Papers.
Geological Society: Nomination Papers
Edinburgh University Library: James Orchard Halliwell-Phillipps Papers.
Institution of Civil Engineers Archive: Nomination papers.
Liverpool University Library: Moor Autograph Letters, GB 141 Moor/524.
Norfolk Record Office: A. B. Whittingham Papers.
Northamptonshire Record Office: Charles Hartshorne Papers.
Royal Society Archives: Nomination Papers.
St Andrews University Library: J. D. Forbes Papers.
St John's College, Cambridge: John Couch Adams Papers.
Society of Antiquaries of London Library: Albert Way Papers.
The National Archives (T.N.A.): C 13/368/25; PRO 30/29/23/14; PCC Wills.
Trinity College, Cambridge Library: Dawson Turner Papers; William Whewell Papers.
Wellcome Institute for the History of Medicine Library: MS 8007.

Bibliography

Adams, C. n.d. The Willis Family of Lincolnshire. Available at http://chradams.co.uk/willis/contents.html. <Accessed 01/07/2016>.

Airy, W., ed. 1896., *Autobiography of Sir George Biddell Airy*. Cambridge.

Anderson, R. D. 1995. *Universities and Elites in Britain since 1800*. Vol. 16. Cambridge.

Annan, N. 1955. The Intellectual Aristocracy. In N. Annan. 1999. *The Dons: mentors, eccentrics and geniuses*, 304–41. London.

Athenaeum. 1840. *Rules and Regulations for the Government of the Athenaeum*. London.

Babington, A. M. ed. 1897. *Memorials, Journal and Botanical Correspondence of Charles Cardale Babington*. Cambridge.

Barlow, P. 1851. *A Treatise on the Strength of Timber, Cast and Malleable Iron and Other Materials*. New ed. London.

Borgatti, S. P.; M. G. Everett and L. C. Freeman. 2002. Ucinet for Windows: Software for social network analysis. Harvard, MA. Analytic Technologies.

Brock, W. 2005. Coming and going: the fitful career of James Cumming. In: *The 1702 Chair of Chemistry at Cambridge: Transformation and Change*, edited by M. D. Archer and C. D. Haley, 138–65. Cambridge.

Buchanan, A. C. 2013. *Robert Willis and the Foundation of Architectural History*. Woodbridge.

Bury, M. E. and J. D. Pickles eds. 1994. *Romilly's Cambridge Diary 1842–1847*. Cambridge.

Bury, M. E. and J. D. Pickles eds. 2000. *Romilly's Cambridge Diary 1848–1864*. Cambridge.

Clark, J. W. and T. M. Hughes eds. 1890. *The Life and Letters of the Reverend Adam Sedgwick*. 2 vols. Cambridge.

Clark, P. 2000. *British Clubs and Societies, 1580–1800: The Origins of an Associational World*. Oxford.

Collini, S. 2006. *Absent Minds: Intellectuals in Britain*. Oxford.

Dade-Robinson, C. 2015. Architecture as Evidence: E. A. Freeman and Harold's Church. In *Making History: Edward Augustus Freeman and Victorian Cultural Politics*, edited by G. A. Bremner and J. Conlin. Oxford.

Dintenfass, M. 1992. *The Decline of Industrial Britain 1870–1980.* London and New York.

Edgerton, D. 1996. *Science, technology and the British industrial 'decline', 1870–1970*. Cambridge.

Edwards, G. and N. Crossley. 2009. Measures and meanings: Exploring the ego-net of Helen Kirkpatrick Watts, militant suffragette. *Methodological Innovations Online*. 4(1): 37–61.

Elliott, P. 2003. The origins of the 'creative class': provincial urban society, scientific culture and socio-political marginality in Britain in the eighteenth and nineteenth centuries. *Social History*. 28(3): 361–387.

Geike, A. 1917. *Annals of the Royal Society Club*. London.

Grafton, A. 2009. *Worlds Made by Words: Scholars and Community in the Modern West*. Cambridge, Mass.

Hall, M.B. 1984. *All Scientists Now: The Royal Society in the Nineteenth century*. Cambridge.

Heyck, T. W. 1982. *The Transformation of Intellectual Life in Victorian England*. London and Canberra.

Lubenow, W. C. 2010. *Liberals Intellectuals and Public Culture in Modern Britain, 1815–1914. Making Words Flesh*. Woodbridge.

Lubenow, W. C. 2015. *"Only Connect": Learned Societies in Nineteenth-Century Britain*. Woodbridge.

McLean, P.D. 2007. *The Art of the Network: Strategic interaction and patronage in renaissance Florence*. Durham, NC.

MacLeod, R. and Moseley, R. 1980. The 'Naturals' and Victorian Cambridge: reflections on the anatomy of an elite, 1851 1914. *Oxford Review of Education*. 6(2): 177–195.

Marsden, B. 2004. 'The progeny of these two "Fellows"': Robert Willis, William Whewell and the sciences of mechanism, mechanics and machinery in early Victorian Britain. *British Journal for the History of Science*. 37(4): 401–434.

Mayer, A. J. [1981] 2010. *The Persistence of the Old Regime: Europe to the Great War*. London and Brooklyn, NY.

Mische, A. 2003. Cross-talk in movements: Reconceiving the culture-network link. In *Social movements and networks: Relational approaches to collective action,* edited by M. Diani and D, McAdam, 258–80. Oxford.

Museum of the Scottish Shale Oil Industry. Charles Humfrey & Son. http://www.scottishshale.co.uk/GazBeyond/BSEnglandShale/BSES_Companies/Humfrey&Son.html. <Accessed 01/07/2016>.

Myers, F. W. H. 1903. *Human Personality and its Survival of Bodily Death*. 2 vols. London.

Rowe, D. E. 2003. Mathematical Schools, Communities, and Networks. *The Cambridge History of Science*. 4. Cambridge.

Pevsner, N. 1972. *Architectural Writers of the Nineteenth Century*. Oxford.

Sanderson, M. ed. 1973. *The Universities and British Industry 1850–1970*. London and Boston.

Shairp, J. C.; P. G. Tait and A. Adams-Reilly. 1873. *Life and Letters of James David Forbes, F.R.S*. London.

Stair Douglas, J. M. 1881. *The Life and Selections from the Correspondence of William Whewell DD*. London.

Todhunter, I. 1876. *William Whewell: An Account of His Writings, with Selections from His Literary and Scientific Correspondence*. 2 vols. London.

Venn, J. 1922–54. *Alumni Cantabrigienses. students, graduates and holders of office at the University of Cambridge, from the earliest times to 1900*. Cambridge.

Whyte, W. 2005. The intellectual aristocracy revisited. *Journal of Victorian Culture* 10(1): 15–45.

Wiener, M. J. [1981] 2004. *English culture and the decline of the industrial spirit, 1850–1980*. 2nd ed. Cambridge.

Willis, M. A. 1868. *A Short Sketch about Washing Linen, and How I Learnt the Modern Art*. Cambridge.

Willis, M. A. 1869. *Science Applied to the Washing of Linen, and to its Effects upon Health*. London.

Willis, M. A. 1871 *A Short Essay on Practical Experimental Philosophy, its Use and Abuse*. London.

The teaching of engineering at Cambridge

Jacques Heyman

Robert Willis was the last Jacksonian professor to give lectures on engineering in the University of Cambridge. He was not the first. Previous holders of the Chair (Milner, Farish) had also covered a wide range of topics in “Experimental Philosophy”, and these included mechanics, metallurgy, chemistry and general applied science, together with more specific practical applications such as the theory of the steam engine. Other Cambridge professors, for example George Biddell Airy, the holder of the Plumian Chair of Astronomy, had also instructed students in similar topics; all gave experimental demonstrations in their lectures. In this they were following the terms of Jackson’s will which endowed the chair. He exhorted the Professor, in his lectures, to present demonstrations.

In fact successive holders of the Jacksonian Professorship, from 1783 until Willis’s death in 1875, while introducing “engineering” topics, had ignored the main thrust of Jackson’s will, which was to teach essentially biological and chemical subjects. (The professors ignored also Jackson’s wish that a cure might be found for the gout.) In the mid nineteenth century demonstrations of the new sources of power —above all, steam engines— were attractive to students, and the Jacksonian professors lectured to large classes. In 1875 the obvious successor to Willis was James Stuart, a formidable mathematician who also had engineering experience, but the University decided that Jackson’s intentions should be honoured more closely, and that a chemist would be a more appropriate appointment. Stuart withdrew his candidature for the Jacksonian chair.

However, the University realized in 1875 that engineering as a discipline had effectively been established in Cambridge, and, with astonishing swiftness, a

new Professorship of Mechanism and Engineering was established. James Stuart was elected as the first Professor. This was the birth of the Department of Engineering, of which Robert Willis must be regarded as the progenitor.

It was during the tenure of Robert Willis of the Jacksonian chair that the stranglehold of mathematics as the qualification for a Cambridge degree was slowly relaxed. Natural Sciences (anatomy, physiology, chemistry, geology) made their appearance. Applied subjects had been discussed and rejected; a single examination paper in Mechanism and Applied Science was eventually established, but it is hard to escape the view that "technology" was regarded with some disdain.

Indeed, from the start of the subject in 1875, and for the next three-quarters of a century, students reading engineering were regarded as in some way pursuing inferior courses to those for the "pure" sciences, and it was not until just before World War II that the creation of the Veterinary school attracted students who were held in even lower esteem than the engineers. (An engineer mends your washing machine; a vet looks after your cats.)

Stuart insisted that his new Department should have a Workshop (which he funded largely with his own money), so that students could have a practical knowledge of engineering in addition to their academic studies. These students, who had always been attracted by the demonstrations of the Jacksonian professors, now had the pleasure of providing their own supplements to what may have seemed rather remote theory. This exposes a perennial problem in the teaching of engineering, and of any professional subject, such as medicine or architecture —a lecture on the science of the subject may seem remote, even meaningless, to the students. The Jacksonian professors addressed the problem with their demonstrations. Willis himself was a master of the art of presentation. His lectures elsewhere on architecture were enormously popular, and were often given in cathedrals, where the fabric itself gave the necessary "visual aids", the demonstrations supplementing the theory.

The Workshops of the Department of Engineering proved to be contentious. They were acknowledged to be useful in themselves, and also, from the start, of great service to the university. They provided equipment for other laboratories, but they were expensive. And there was the persistent view that it was somehow not respectable for a student in a great university to engage in mechanical tasks. This view is no doubt a reflexion of the standing of engineering in the UK from the nineteenth century until the end of World War II —a view very different from that of most of continental Europe.

In the UK the standard route of education of a professional engineer was by an apprenticeship in Industry, by study at night class, and finally by examination, at degree standard, by one of the Institutions (of Civil Engineers, Mechanical Engineers

and so on). These Institutions gave exemption from their theoretical papers —but not from the requirement of practical experience— to those few candidates, before World War II, who had an engineering degree from a university. After World War II these Institutional examinations were abolished, since the overwhelming majority of potential candidates now had university degrees. Acceptance by an Institution confers Chartered status; the engineer is "licensed" to practise professionally.

So, after World War II, the training of engineers in the UK became the responsibility of the universities. There remained, and continues to remain, the same problem of the teaching of theory to students whose interest must be continuously stimulated at a time before they have had any real contact with the world of engineering. This is a particular concern for the kind of student taught by Willis in Cambridge, and continuing to be taught in the major universities today. These students are very bright, and have gained admission by outstanding performance at school. They can be taught almost anything, and there is a heavy responsibility on those who arrange the courses to provide the best possible teaching. The fact is, however, that no matter how these bright students are well or poorly served by the university system in general, and by the instruction given in a particular engineering department, they will stay bright. They will be sought after by engineering firms, and they will make good in those firms. There is a benevolent spiral. A good engineering school is known to produce good engineers, and so good students will join that school in that university, and they will then prove themselves to be good engineers in practice.

From the start of the engineering school at Cambridge in 1875 through to the 1950s, all students were required to study all engineering subjects, and to take compulsory examination papers in all of these. (There were some minor exceptions of specialist papers in the final year, but these were optional.) The supervisors of these students, in the much valued tutorial system, were therefore also required to teach all subjects —the expert in fluid mechanics had also to teach electrical circuits, thermodynamics and the theory of structures. This led to considerable inbreeding, in the first half of the twentieth century, of the senior members of the Engineering Department. To become an effective teacher, the Lecturers had themselves to have survived the same wide engineering courses. Indeed, the examinations became almost mandarin; the papers were identical from year to year, although of course they did not quite present themselves in that way to the candidates. A question involving electrical circuits would replace the words "thermionic valve" by "transistor", but would otherwise be unchanged.

The engineering courses were in fact set in the medieval pattern. There was an established body of knowledge —which, to be sure, was subject to slow change— that had to be mastered by students if they were to proceed to the Bachelor's, and then the Master's, degrees.

The present

With such a wide range of subjects in a general engineering course, each of the individual disciplines will be taught with the intention of exposing their scientific bases. This implies that there is little time to engage in the discussion of practical problems. To be specific, and to examine, for example, the education of the civil engineer, there will be no room to discuss the slope stability of soils, the shearing stresses in thin-walled steel boxes, or the initiation of cracks from notches, to give but three instances where ignorance at a fairly elementary level led, in the last century, to well-known engineering disasters.

Professional training is in fact acquired after leaving the university, in the traditional master/pupil relationship in Industry. The examinations set by the university have only marginal relevance to the acquisition of this practical expertise; in essence, they have been a set of hoops through which the student has been made to jump, very much like those which had been jumped to get to the university at all. The student's brightness has already been established, and there is no need of the university hoops to confirm this. The student's time would be better employed in learning more of the intellectual and practical skills required by a chosen branch of engineering.

These considerations also arise in similar ways in other professional schools. In debates as to whether or not universities are the proper places for vocational training, it seems to be often unnoticed that, for engineering at least, many universities do not actually give vocational training. A university is a home of scholarship, of learning and of research, and its teaching is inevitably directed to the creation of scholars who will carry on these activities. This is clear in such subjects as history or english; some of the top quarter of students who get first-class degrees may in turn eventually teach in universities, having firdt spent some time in research, and a few may teach in schools, but by far the greatest number of graduates in these subjects will enter professions where little direct use is made of what they have been taught.

This pattern is also true of the engineering schools in universities, but with one difference. Engineering courses serve to determine the next generation of engineering scholars. Some of those who pass the examinations, the top quarter of the students, may go on to do research, and may hope one day to advance the science of engineering. The other three quarters, who, to judge harshly, have failed the tests —that is, the typical products of the university— go on, in the case of engineering, to practise engineering. This is the apparent difference between a professional school and an arts school such as history.

(It may be noted, in passing, that there is some evidence that a lower-than-average performance in the final examination correlates to some extent with a

better-than-average performance in real life as a practical engineer, and certainly a pass degree should not be despised by Industry. This may be no more than a slightly unfortunate consequence of the fact that engineering courses are taught by professors who are very keen to teach their subject in depth, and the evidence is that this has been so ever since the establishment of engineering schools (in France) in the eighteenth century. Professors teach what they themselves find of interest, rather than what is necessarily useful.)

The future

In Cambridge the traditional three-year course, of the kind which leads to a Bachelor's degree and with which Robert Willis was familiar, was replaced twenty-five years ago by a four-year course. The bachelor's degree is still awarded after three years, but successful completion of the fourth year leads to the degree of Master of Engineering. The first two years of the new course are still essentially broad, with all students being examined in a wide range of subjects. The second two years, however, permit specialization,, with the mastery of some fairly deep theory. This can cause distress to those not in the top flight of the class, but there are compensations. There is time not only for fundamentals, but, for the intending civil engineer, the description (both mathematical and phenomenonological) of slope stability, of shear stress and of metal fatigue. Not only the potential scholar but also the potential professional engineer will obtain a deeper understanding of a particular branch of engineering science.

There is indeed a body of knowledge called engineering science which is different from the knowledge required to practise as an engineer, but they overlap and one is essential to the other. The science of engineering must be taught in universities, but the evidence seems to be that there is a large number of clever students who do not, one way or another, really wish to master this science. This is a view from within a university, and is perhaps contentious.

Viewed from outside, it seems clear that Industry needs a large number of clever engineers, but not necessarily engineers deeply versed in the science of their subject. Attempts to instil this deep science, of which little or no use will be made, are clearly wasteful. The basic engineering knowledge to serve the intending professional engineer can be taught in two years. The teaching programme for such a two-year course requires very careful planning, with every precaution being taken to maintain the students' awareness of the relevance of what they are being taught, but at the end of the two years they will have a firm foundation on which to base the practical skills learned in Industry. It is from the students in the second two years of a four-year course that the next generation of "scholars" will come.

Lessons can perhaps be learned from history. The medieval professional route, of a stonemason for example, was from apprentice to journeyman to the career grade of master. A very few of these masters could progress further by being taken into the "office", where they learned the deeper "theory" of their trade, and they could finally take charge of a major project. There is a case for following such a programme for the training of today's engineers. The two-year basic university course is the "apprenticeship"; the period spent in Industry acquiring relevant practical skills is the "journeyman" phase; acceptance by one of the Institutions as a Chartered Engineer corresponds to the attainment of the career grade of "master". If they so wished, some Chartered Engineers could return to University for a second two years, where they would master the advanced theory so necessary for a deeper understanding of the professional work in which they are engaged.

Such a radical programme would require a massive upheaval in the tertiary education system in the UK, and there would be many objections. Certainly some of these would be voiced by students; if a four-year course leading to a Master's degree were on offer, there might be reluctance to settle for an "inferior" two-year course. However, if the University decided that two years would qualify for a bachelor's degree, and if the engineering profession would accept that such a degree, followed by appropriate practical training, would lead to Chartered status, then very many students might well decide to enter the real world as soon as possible. They could then, if they chose, return later for two years to university to prepare them for leadership of their profession.

Acknowledgements

Extensive use has been made of:

Buchanan,A, 2013. *Robert Willis (1800-1875) and the foundation of architectural history.* Woodbridge (The Boydell Press).

Hilken,TJN, 1967. *Engineering at Cambridge University 1783-1965* (Cambridge University Press).

A Protean system of apparatus: Robert Willis and the material invention of mechanism

Ben Marsden

Elsewhere I have examined the origins, reception and appropriation of Robert Willis's *Principles of Mechanism* (1841) and the connected ambitions of Willis and his Cambridge collaborator William Whewell to use mathematical conceptions of machinery to initiate a reform of the early Victorian engineering profession (Marsden 2004). As a complement to that earlier examination of principles and "words", here I examine Willis's pedagogic practices and "works", focusing on his design, use and dissemination of apparatus especially designed to inculcate mechanical philosophy. I begin by considering Willis's attempts to mechanize specific technical skills. I then explore the culture of gentlemanly mechanical practice in and around Cambridge in the 1830s and 1840s. The next section investigates the broadening of Willis's scientific, engineering, governmental and pedagogic networks through to the early 1850s. A discussion of Willis's subsequent collaborations, with government and with manufacturers of educational apparatus, shows how his "material aids" of mechanism were disseminated on a national scale.

Mechanizing skills

In early life, Robert Willis copied engravings of instruments and machines from the *Transactions* of the Society of Arts,[1] worked to perfect the pedal harp he patented in February 1819,[2] and equipped himself as a gentleman inventor. He bought books on practical mechanics and mathematical practice; he collected materials, tools, and instruments from high-class London instrument makers;

and, where his own boyish skills in carpentry and mechanics failed him, he paid for assistance (Willis 1856). In the 1820s, Willis famously debunked von Kempelen's automaton chess player, a life-sized "mechanical Turk" that had toured Europe with its keepers since the 1760s (Eales 1985, 123, 129–31; Standage 2002). Once in Cambridge, Willis found a niche as a *de facto* curator of experiments, lecturing on mechanical science at the Philosophical Society, focusing on sound —and even producing a mechanical model of the larynx.

But Willis's exhibitions, although gentlemanly, were not those of a dilettante. His early machines attempted to embody skill —and replace human artisans. Like John Herschel and Charles Babbage, Willis constructed machines to carry out practical, mathematical and even intellectual tasks (Cannon 1978, 35).[3] Their names rooted them in the classical culture so celebrated by William Whewell. The "orthograph" (1830–34) mechanised the representational practice of projection (Clark 1889–92, xxxiii and xxxviii). A "tabuloscriptive engine" (1837) devoured tables of numbers, of the kinds produced by Whewell's tidal surveys and Babbage's business-minded astronomer friends, and unmediated by the wilful human calculator or draughtsman, spewed out paper graphs "very readily legible and intelligible" (Clark 1889–92, xli; *Philosophical Magazine*, 10 (1837): 486; Robson and Cannon 1964, 181–4; Cartwright 1999, 110–17). The "cymagraph" replaced the trained eye, the compass, lead tape, or clay to trace with "the most perfect accuracy" Gothic architectural mouldings in all their "astonishing spirit and freedom" (Willis 1842a, Willis 1842b). A letter balance answered new Post Office legislation and provided a crutch for the clerical brain by automatically rounding up to the nearest ounce and indicating directly the stamp required (British patent no. 8384 (12 February 1840); "Willis's patent letter balance", *Mechanics" Magazine* 33 (1840): 148–9). A series of cams, worked by a handle, could even write —the single word CAM— in Cambridge (Grenville 1928, 15).

The best-documented of Willis"s attempts to automate human skill was the "odontograph". In 1837, as part of a programme to analyse gears and to promote "involute" rather than epicycloidal teeth, Willis informed Liverpool mechanics that, thanks to his mathematics, toothed cast-iron (rather than wooden) gearwheels might be standardised and more easily marked out so that any two of a set could work together truly (Willis 1837; Robson and Cannon 1964, 179; Woodbury 1958, 23–31). (Metal gearing required greater precision in construction than the wood it was gradually replacing.) The result, he told the Institution of Civil Engineers, was a "system more easy of practice for the workman" (Willis 1838a, 93). Astronomer Royal George Biddell Airy was only one of the more recent mathematicians to elaborate the daunting geometry of toothed wheels in the abstract (Airy 1825). Willis now put maths in the service of the engineers to meet "the requirements of modern construction" (Willis 1838a, 89). In 1838 he previewed

"the practical means of carrying out the theory" in an "exhibition of mechanical inventions" organised by Charles Wheatstone, David Brewster and Babbage for the British Association for the Advancement of Science (BAAS): this "odontograph", embodying Willis's geometrical labour, constituted a "practical solution" enabling, at least in theory, the workman to do "at once" what before had taken skill and time (and, in particular, to lay out involute gear teeth) (Willis 1838b, 154; Holtzapffel & Co. 1838, 9; Willis 1841, 131). By 1842, according to one anonymous technical commentator, Willis's "important and well written paper" on the teeth of wheels was "already well known" ("Review [of Rennie 1841, which reproduced Willis 1838b]" in *Civil Engineer and Architect's Journal* 5 (January 1842), 28–9). Practical men could copy the odontograph from the *Principles of Mechanism* (1841) or they could buy it in card-paper or metal from Holtzapffel's shop on Charing Cross.[4] Later, they were used widely in factories and, from 1852 sold by the company Brown and Sharpe (Woodbury 1958, 28).

Of course, the mechanics were quite able to generate politically radical philosophies of their own practice resisting the encroachments of mathematicians who sought to automate and snatch skill (Morus 1996). In practice, although Willis's odontograph was a tool good enough for the engineers, practical rules of procedure were still required for the shop men working with the compass and scale (Woodbury 1958, 31); and epicycloidal teeth, not Willis's more efficient involutes, continued to dominate. All the while, however, Willis was attempting through mathematics to expand the role of the schooled engineer and to make skilled tasks peculiar and profitable to the machine maker redundant (Willis 1838a, 105; *Newcastle Daily Chronicle*, 27 August 1863). If engineers and artisans outside Cambridge were lukewarm about Willis's ideas, could Willis train a sympathetic, learned and also practical, breed of engineering enthusiasts within Cambridge?

The cultural practice of mechanism in and beyond Cambridge

Willis's forays into material mechanical invention raise the question of the relationship between the symbolic demonstrations of the kinematics enshrined in the *Principles* and the practicalities of grappling with mechanism in, and beyond, the Cambridge classroom. Retiring to the study, aided by the professional coach, Willis's gentlemanly students certainly crammed the mathematics of "pure mechanism". But some, like their professor, boasted a surprising degree of practical skill.

Willis always encouraged, by his own example, direct engagement with, and even construction of, practical machines and their parts by his students and followers. In 1872 he said he would eschew the polished brass of the elite philo-

sophical instrument maker for “a little iron wire” of his own to make himself an apparatus maker (Royal Commission on Scientific Instruction and the Advancement of Science 1872, Q. 4698; hereafter RCSIAS). The more affluent Cambridge students had their own tools. John Venn, who studied maths with William Hopkins and Isaac Todhunter in the 1850s and likely attended Willis’s lectures, had a wooden turning-lathe as a child (Francis 1923, 6–7). Old Etonian Neville Grenville “chummed up” with Willis before coming up: together they entered Grenville’s workshop to toy with “a nice little Holtzapffel lathe”. Holtzapffel & Co. was the most successful amongst the producers of lathes for amateurs and the company astutely wed mechanical practice, scientific intellect and gentlemanly vanity. Amongst their products were increasingly elaborate lathes including deluxe models, with mahogany frames, retailing at £260 (Holtzapffel & Co. 1849, i). Purchasers could visit their premises at 64 Charing Cross Road in central London to learn the arts of turning under up-market supervision from experienced workmen; or skilled men would be sent out to teach these amateurs “at their private residences, in town or country” (Holtzapffel & Co. 1849, v). In 1851, the jurors of the Great Exhibition led by Willis would praise just such “a first-rate amateur lathe”, with apparatus and tools (Willis 1852a, 200, 204).

Willis had persuaded the mother of his young charge and “brother blacksmith” Neville to buy Holtzapffel’s *Turning and Mechanical Manipulation* (1846–50) (Grenville 1928, 14). The relationship between philosophers of mechanism and mechanical practitioners was deep. Willis and Babbage had both contributed signed articles to this technical manual; Babbage even lent Holtzapffel tools (Willis 1870, endpapers listing works; Holtzapffel to Babbage, 1 and 3 July 1846, Add. 37193, ff. 290–92, Babbage Collection, BL). Holtzapffel was careful to encourage such interactions, flattering potential clients:

> The cultivation of Mechanics by Gentlemen who have the advantages of general acquirements and of leisure, has given rise to many ideas and suggestions on their part, which have led to valuable practical improvements … In some cases H. and Co. have been furnished by Gentlemen with the theoretical and general sketch of machines, the details of construction being entrusted partially, or wholly, to themselves; and in others they have merely carried into practical effect the finished designs (Holtzapffel & Co. 1849: v).

Holtzapffel delivered the mechanical offspring of Willis, Babbage’s cutting tools, Henry Moseley’s “indicator” (which measured work done), and the geological hammers of gentleman of science John Robison: mechanical manufacture and marketing merged with technological vanity publishing. For gentlemen shy of the patent system, unwilling to prof too directly from mechanical science, or

unable to capitalize a manufactory, Holtzapffel tactfully introduced their mental products into public practice, re-imagined as altruistic acts.

So in the Jacksonian classroom in Cambridge, neither students nor professor need be worried about getting their hands dirty with real machines. In the lecture theatre, Willis would bring out a tremendous array of models, deployed as material intermediaries, sanitizing the realities of mechanical practice. These he constructed, exhibited, and actively manipulated in lectures delivered each Michaelmas term even to those students who had mastered "only the ordinary forms of mathematics". Stronger students matched maths with model by reading "the chapters which belong to the machines and contrivances that I have exhibited to them" (RCSIAS 1872, Q. 4658).

Willis justified these performances with pedagogic tools on historical grounds even though he was aware that his contemporaries had brought the use of such devices to a state of diverse perfection. Discoursing before the Society of Arts, he saw "two kinds of … investigating philosophers": mathematically educated pure reasoners, unconcerned with the practical correctness of their deductions; and those like Willis who "delighted in trying the results of their deductions … all of which they could account for most thoroughly". They wanted to make their results "easily intelligible"; and they found that the very process of illustrating their "striking results" using apparatus itself encouraged them to look for and appreciate the reasoned explanations of those results in terms of "simple natural phenomena" (Willis 1856). Willis approved of the demonstrations of earlier natural philosophers, including J. T. Desaguliers and James Ferguson; equally he was aware of contemporaries like T. Sopwith who offered geological students and "owners of mineral property" sets of geological models "divested of technical terms and abstruse speculations" for between £2 and £5 (Sopwith 1841, vii).

But Willis's chief local inspiration was William Farish: active "just at that era when machinery was being developed for the purpose of manufactures", Farish had given mechanical demonstrations to his Cambridge class (RCSIAS 1872, Q. 4657). He had, Willis explained, "contrived a system of apparatus", including gear wheels, axles and other mechanical parts, "by which he could build up the machines that were required from day to day" as students looked on (RCSIAS 1872, Q. 4657; Farish's lectures "On the Construction of Machines" (part III of his course) are discussed in Hilken (1969), 42). When he took over as Jacksonian professor, Willis found Farish's "idea of a Protean mechanism" was a good one, but that his models were "somewhat embarrassed and complicated" (Hartenberg and Denavit 1964, 71). Like other Victorian science professors resigned to accumulate material teaching capital, he dipped heavily into his "own private purse" (RCSIAS 1872, Q. 4659), soon devised "another system of building up" (RCSIAS 1872, Q. 4657), and capitalizing on the "facilities which the improved state

of machine-making afforded", found the "idea" could be carried out in a way which was more complete, more useful and "of a more extensive application to philosophical apparatus" (Hartenberg and Denavit 1964, 71–2, quoting from Willis 1851). Willis eventually claimed that, with that apparatus, he could exhibit every example he could "get or imagine" (RCSIAS 1872, Q. 4657). So versatile was his system that "when a new contrivance arises, or I discover it in an old book, or out of my brain, I can build it up immediately, and exhibit it to my audience" (RCSIAS 1872, Q. 4671). Willis would synthesise complete machines of all kinds from standard mechanical elements in real time in front of his audience.

By the end of his teaching career, Willis had a Jacksonian lecture room with generous space for audience, apparatus and storage (Hilken 1969, 40), unlike the cramped surroundings grudgingly accepted by other academic colleagues including Lewis Gordon in Glasgow (Marsden 1998). With the right museum of individual machines, Willis could reduce mechanical industry to the size of a well-stocked apparatus room. But more remarkably, in a second condensation, each model could be analysed into constituent parts. There was no need to store each distinct machine separately; all possible machines could be reconstructed from a reservoir of standard elements. Making machines intelligible, or exhibiting mechanism, in this reductive way emphasised and valued the enduring, transferable, and mathematically ideal.

It is important to recognise the ways in which such academic performances sought to open up the secrets of art and worked to make the complex appear simple. In 1841 Willis had characterised practical mechanical skill as a "species of intuition", available only to the "experienced"; but those who had it were, too often, "totally unable to communicate [it] to others" (Willis 1841, iii–iv). Farish, in contrast, had built up complete machines in "the simplest, almost approaching to infantine, manner", so that the student could not but "smile at the seeming facility of the subject" ("Socius" quoted in Hilken 1969, 43). Willis claimed that mechanical motions demonstrated in the Cambridge classroom by models required "very little teaching and explanation" (RCSIAS 1872, Q. 4666).

The eventual appearance of openness and simplicity had come at the price of iterative design improvements, creative selection of what subset of actual machines to show, and collaboration with technicians. Willis spent years developing the system of apparatus that replaced that of Farish, and also in choosing the machines best suited to his scheme of demonstration. When he listed the main examples in an early *Syllabus* (1839), he concentrated on machines which "admitted the best of being put into the form of demonstrative models" (Willis 1839, 3). The next year, Willis illustrated his "outline of the Elements of Mechanism" with machines selected to "exemplify the different branches of the subject" and chosen to "excite and fix attention" by virtue of construction or process demonstrat-

ed (Willis 1840). The apparatus did not make itself: Willis called upon not quite invisible technicians like the carpenter, "John", who assisted him in Cambridge in the 1860s (Grenville 1928, 14; Shapin 1989). When Willis said he was "in the habit of constructing his own apparatus" he meant not that he personally could "cut down a tree, saw it into planks, and plane them up" but that he "employed workmen to construct from his own design, in separate pieces". Willis would put those "separate pieces" together —having almost entirely separated others' manual skill from his intellect (Willis 1856).

Finally, like his friend Michael Faraday at the Royal Institution, Willis only perfected these regimes of demonstration with practice —and with assistants' help. He rehearsed "with painstaking diligence", at the time of the performance rarely using notes yet speaking, contemporaries insisted, with "simple and effective eloquence" (*Newcastle Daily Chronicle*, 27 August 1863). He eschewed, like Faraday, the "modern methods of clap-trap" (*Cambridge Chronicle and University Journal*, 6 March 1875), distancing himself from the religious and mechanical "enthusiasts" of London's Exeter Hall, and the extravagant displays of reform-minded electrical showmen (Morus 1991; Morus 1992). But even in these demonstrations Willis had help: "Naturally", each professor had his "different man"; where the anatomy professor had a medical pupil, Willis had a paid workman to set the models in motion (RCSIAS 1872, QQ. 4671–2).

Such performances, reaching for openness and simplicity, in fact relied upon hierarchies of inventive intelligence, mechanical education, practical skill and social class. Only studied self-effacement, and a team of supporters, made Willis a seemingly transparently medium communicating the intricacies of the mechanical world. Only preparation and selection made mechanical engineering as easy as child's play. Securing and owning knowledge in this way emphasised the central role of those gentleman scholars who, in Cambridge, Oxford and London had drunk deeply at the well of pure and positive mathematical knowledge (Morrell and Thackray 1981).

Networks of mechanism: association and dissemination

An associational history reinforces this account of Willis's pedagogy. From the late 1830s Willis's authority to dictate and demonstrate the "principles of mechanism" accumulated, at least in elite circles, as he entered the main scientific associations with the support of key "gentleman of science". The "Cambridge network" worked to ensure Willis was clubbable, audible and visible, beyond the Fens (Cannon 1978, 29–71): Herschel, Whewell, Adam Sedgwick and J. W. Lubbock eased him into the Royal Society of London in 1830; Sedgwick signed him up to the Geological Society in 1831; Whewell booked Willis to report on sound

for the BAAS soon after its formation (Morrell and Thackray (1984), 54 and 96; Morrell and Thackray 1981, 123). Willis would claim that it was Cambridge that had made the British Association mature when it met there in 1833 (Willis 1862: lii). It was clearly Cambridge that had given Willis a national profile amongst the "gentlemen of science", even if he was never quite at the very heart of that coterie (Morrell and Thackray 1981, 23).[5]

By the autumn of 1837 he was Vice-President of the new "Mechanical Science" Section of the BAAS, the creation of which, he also insisted, was the Association's only significant structural change since its first assembly in Cambridge in 1833 (Willis 1862: li; Morrell and Thackray 1981, 256–66).[6] In May 1838 the mechanical engineer Joshua Field welcomed Willis into the Institution of Civil Engineers as an Honorary Member, signalled his status as philosopher rather than practitioner of machinery. [7] Three thousand flocked to hear his discourse at the Newcastle meeting of the BAAS (Morrell and Thackray 1981, 197). The assiduous cultivation of mechanical engineers, like William Fairbairn, and experimental mechanical philosophers, like Eaton Hodgkinson, who had allied themselves within the BAAS meant that by 1843 Willis could offer Babbage introductions to the men he was now calling "our friends": the inventor James Nasmyth and the precision mechanical engineer Joseph Whitworth (Willis to Babbage, 18 December 1843, Add MS 37192 f. 475, Babbage Collection, BL). In Section G, the relationship between engineer and philosopher was symbiotic. The engineers provided the BAAS with the spectacle of industry and added plausibility to its claims that real public utility derived from its programmes. This was the right platform for Willis's claims of a union of practical mechanics and the "mechanical science" of which the science of "pure mechanism" was to provide the systematic key.

By 1851, Whewell's acolyte James David Forbes, himself a keen advocate of academic engineering, was flattering Willis for his "extensive acquaintance amongst Theoretical and Practical Engineers" (Forbes to Willis, 9 April 1851, Letter Book V f. 45, Forbes Papers, University of St Andrews Library). By then Willis's influence extended far beyond Cambridge and he had infiltrated national institutional and entrepreneurial networks of mechanical engineering power. If his ideas had spread in part by the printed word and especially the *Principles of Mechanism*, there was as ever a complementary material side to Willis's work, manifested in the ad hoc dissemination of his apparatus to followers outside Cambridge and also in his diverse work in connection with the Great Exhibition.

To disseminate his system of apparatus, Willis approached at least one talented Cambridge student who went on to occupy considerable influence in nineteenth-century natural philosophy. In November 1849 Willis told William Thomson, who was by then had a chair in Glasgow, about a prototype of his system.

Holtzapffel had made a set of “cast iron frame pieces” and sent them to Thomson; one had gone astray but it was “so simple” that the young professor could (even) “get it made at Glasgow”. The pieces were to be assembled and then bolted to a secure surface; Willis had already shown Thomson their “stud sockets” for “revolving wheels pullies &c.” The frames could be put together “in combination in a great number of ways, to hold any parts of apparatus”. Willis promised to write Thomson “a small code of instructions” (Willis to Thomson, 14–17 November 1849, Add MS 7342 W129, Kelvin Papers, CUL).

Something like that “small code” soon appeared as *A System of Apparatus for the Use of Lecturers and Experimenters in Mechanical Philosophy* (1851) —a complete description of the kit into which Willis had invested so much time and labour (Willis 1851). In a list of “Mine own inventions” Willis registered this “Complete system of so-called Protean Apparatus of pieces for building up frames & machinery” (Add 5133, f. 110, CUL). (The sea-god Proteus could take on many and various forms at will.) Owners of this “system” could construct machines like those discussed in the *Principles of Mechanism*, complete other machines, prepare apparatus for experimental mechanical philosophy, and even try new combinations of elements in original research. The “system” was a kit for display —but also for invention, as promised in the *Principles of Mechanism*. Willis turned to Holtzapffel to construct it (Willis 1851).

The publication of that code, which was itself an admission that the demonstration apparatus required skilled interpretation, coincided with the launch of the Great Exhibition, packaging the practical arts of all nations in a “palace of industry” in Hyde Park between May and October 1851. Willis had helped to draft the *Circular issued by Her Majesty’s Commissioners describing the Objects of the Great Exhibition*. Known as a philosopher of machinery, Willis helped to dictate the classification for the exhibits. Of the four main sections, the third was machinery; that, in turn was divided into six subsections. The second subsection (Class VI) was “manufacturing machines and tools” and for this section Willis was to be a juror and Deputy Chairman, working beside the Chairman J. V. Poncelet, a noted technical writer and pedagogue (Willis 1852a).[8]

Willis offered two commentaries on the “results” of the Exhibition. The first was a report on Class VI. The jurors were asked to evaluate this particular class according to fitness to purpose, cost, durability, workmanship, running costs, perfection of articles produced and other categories (Great Exhibition 1852). In 1862 Willis would commend the “magnificent collection of machinery in the Great Exhibition” (Willis 1862: lxi); but his report of 1852 emphasised disorder, incomprehensibility, and incompleteness (Willis 1852a). The gulf between this collection and the carefully constructed system of Willis’s classroom was vast. Instead of the best of all industries of all nations, the result was a “collection of

miscellaneous articles" allowing little systematic evaluation or discussion of the "relative standard of excellence". The meaning of machines remained hidden when, as was often the case, "the exhibitor is neither to be found, nor has left any representative capable of explaining them". Some processes (for textiles, machine tools) were superfluously illustrated whilst others were omitted. Willis noted, perhaps without irony, that machines unfitted to the wants of a "crowd of spectators" were absent: anything attended with "excessive noise, dust, disagreeable smells, splashing and spilling of water and other liquids, or similarly annoying phenomena"; anything requiring too much time, or care, or heat; anything too large, too valuable, too fragile. The exhibition did "not represent the real extent to which machinery is employed in the manufactures of this country", or in foreign countries (Willis 1852a, 194–5).

Some order could be imposed and some enthusiasm could be mustered by discussing the machines according to their function: first, those for making thread, then for weaving, then for printing and paper making. Section (D), the "working parts of machines" provided the opportunity for Willis, in kinematic mode, to remind readers that: "In all machines there are certain parts which actually do the work for which the machine is constructed, the mechanism serving merely to produce the proper relative motion of these parts to the material upon which they operate, and those working parts being the tools with which the machine operates" (Willis 1852a, 199). Willis was most enthusiastic about the engineers" tools —or machine tools, especially those made and exhibited by Whitworth. Lecturing at the Royal Society of Arts in January 1852 on the "results" of the Exhibition, Willis moralised machine-tools as central to the fashioning of a strong economy and a vibrant empire. He also repeated the mantra, often heard at the BAAS, invoking a more intimate union between scientific and practical classes so that each might then assist in the perfection of the other (Willis 1852b; Emmerson 1973, 116). That hoped-for union, a harmony of theory and practice, was to be facilitated through engineering education in industrial centres —although not, or not yet, in Cambridge (Marsden 1992; Hilken 1969).

Although, despite the many impacts of the Great Exhibition on technical education, there was to be no chair of engineering in Cambridge, Willis's enthusiasm for teaching had anything but dwindled. In 1853 Henry De la Beche recruited him to a new government-funded professorship in applied mechanics at the young Metropolitan School of Science applied to Mining and the Arts (later the Royal School of Mines) on Jermyn Street. This seminary for technical experts attracted no more than fifteen full-time students per year in its first decade (Chambers 1896, xviii–xix and xcii–xciii; Reeks 1920, 63). Robert Hunt, who had been lecturing on mechanical science and its applications to mining, took over the teaching of physical science, leaving Willis to expand the teaching of mechanism

in line with his Cambridge lectures. Edward Forbes trilled at the appointment "to our corps" of such a celebrity, "so eminent a philosopher", and "a new source of strength, whose value cannot be too highly reckoned". Of few appointments could it be said, as Edward Forbes said, that Willis would be approved in the worlds both of "science" *and* of "mechanical industry" (Chambers 1896, xix, quoting Forbes in October 1853).

The School of Mines offered Willis popular and professional audiences larger than those Cambridge could muster. Between 1854 and 1867 he gave an annual course of 36 lectures and, every other year, six lectures to working men (*Newcastle Daily Chronicle*, 27 August 1863). Who attended these lectures? Karl Marx had visited the Great Exhibition and had also read an SPCK survey *The Industry of Nations* (1852–55) that echoed Willis's sly re-definition of "mechanism" in the jury's report;[9] but Marx found it hard to comprehend the complexities of machinery. He confided to Engels in January 1863 that he found it far easier to grasp the laws of mathematical mechanics than to understand the simplest technical reality. For clarification, he went not to the workshop, but to Willis's course of practical lectures for workers (Yoshida 1983a, Yoshida 1983b, 87). With what impact? Andrew Ure's *Philosophy of Manufactures* had, from 1835, recommended self-acting machines to the industrialist to displace unruly artisans (Ure 1835). From his first lectures in 1837, Willis had likewise informed students (like Stokes) about the "self-acting" mule as a replacement for the female spinner's skills as "the same thing done by machinery" but not yet enough to banish strikes or high wages since the "winding up in the mule requires g[rea]t dexterity". There is every reason to believe Willis continued that line of thought in his Jermyn Street lectures; and, mentioning them in his Report on Class VI, he may have reinforced the ideas about self-acting machines, especially the nearly intelligent Jacquard loom, which were central to Marx's account. Willis's definition of mechanism certainly entered Marx's *Machinery manuscript* (1861–63) and, through that sketch, *Capital* (Yoshida 1983a, Yoshida 1983b).

"The material aids of education": exhibiting mechanism

The Jermyn Street job coincided with new moves by Willis to replicate, disseminate and institutionalise his models —together with his conception of the best arrangement of mechanical expertise and innovation. The Commissioners of the Great Exhibition, the Board of Trade and then the Department of Science and Art (established in 1853 to co-ordinate the training of science teachers), jointly encouraged Willis to develop the apparatus which constituted the material counterparts to the theoretical structures of the *Principles of Mechanism*. Specifically, in a response to pressure for the revision of scientific and technical education at all

levels, the Board of Trade commissioned Willis to consider “the construction of a better sort of apparatus for the purpose of illustrating the elementary principles of the mechanical sciences, than that which had hitherto been employed in the ordinary schools throughout the country” (Willis 1856). This represented an amplification of Willis’s original plans, extending his performances at Cambridge and London institutes to tackle elementary education.

That call grew out of the Great Exhibition. According to the managers of the Royal Society of Arts, although *pace* Willis, the Exhibition of 1851 showed that the simple accumulation of objects under a single roof stimulated progress by exhibiting the perfection attained and providing the opportunity to systematize the hitherto miscellaneous. In the summer of 1852 the RSA called for an “Educational Exhibition” to inject efficiency into education by the same strategy of collection and arrangement. In 1853 there was a small “Exhibition of Educational Apparatus” at the Mansion House in London. The next venture, accomplished in July 1854 and again sponsored by the RSA, was to bring together at St Martin’s Hall in London the material pedagogy of the United Kingdom, the largest colonies, the leading European countries, and the United States —duty free, thanks to the Foreign Office (Yapp 1854, 5–6).

Elementary education was, the *Athenaeum* commented, a subject of “violent disputes, —not merely about principles and plans, but about matters of fact”. It was necessary to put an end to “random guessing, daring assertion, furious contradiction, and hopeless uncertainty”. An exhibition would be the opportunity to observe and decide; to discover whether Britain was behind its neighbours and, if so, to learn how to rectify the situation; to assess the relative merits and programmes of the various educational bodies (Department of Science of Art, Committee of Council on Education, National Society, British and Foreign School Society, Home and Colonial School Society); to stimulate improvements through the rivalry of juxtaposition. There was much to observe: amongst the apparatus, patent furniture, model schools and books, the Prince of Wales fielded three cabinets (one illustrating cotton manufacture, the other two showing specimens from natural history used in commerce). Commodities produced by the blind, the idiot, the ragged and the colonial, variously rectified by institutional regimes, evidenced the power of proper training for economic production (“The educational exhibition”, *Athenaeum*, 8 July 1854).

As with the Great Exhibition, there was no shortage of interpreters. In *conversazioni* and widely publicised lectures, secondary orators pontificated on the potential of the “idiot” and the inculcation of “common things” (Sidney 1854; Dawes 1854); but the proceedings formally began with William Whewell’s extensive gloss on “the material aids of education”. In a climate of dispute and rivalry, Whewell chose not to endorse particular educational crotchets, commend

specific suppliers, or ally himself to transitory rival schemes. Whilst recognising the value of the exhibition, he urged caution: no radical changes in teaching practices were being suggested or sanctioned; any special professional or technical education must (as he had so often said before) be built upon a general liberal education fostering an enduring culture and a love of truth. Though surely endorsing the exhibition, Whewell insisted that "there is no apparatus which is so necessary" to assist education as "language": the best material aids were thus the dictionary and the primers in classics and in geometry (Whewell 1854, 18).

Whewell barely mentioned his friend and former collaborator Willis's terrain: the power of models to inform or illustrate. The harmonious marriage of Whewell and Willis, two "Fellows" producing the progeny of their textbooks, had primarily been in the minds of sarcastic reviewers (Marsden 2004). Lecturing on the Great Exhibition in November 1851 Whewell had admitted astonishing advances revealed over a vast historical panorama (Yeo 1993, 224); but Whewell became increasingly pedagogically conservative in later years (Mertens 2000; Yeo 1993, 224–30; Becher 1995). Whewell admitted to J. D. Forbes, shortly after his talk, that he was losing touch with the new men of science in London; with scarcely a day spent in London that year, he had, nevertheless "been persuaded to give two inaugural Lectures … They contained my ordinary general views with a few illustrations, but they seemed to be accepted as answering their purpose" (Whewell to Forbes, 28 July 1854 in Todhunter 1876, ii: 403). Had they? One commentator was disappointed that Whewell's remarks lacked a "more definite and practical character" —a consequence, he believed, of Whewell's failure to tour the exhibition before preparing them (review of Whewell 1854 in *Athenaeum*, 26 August 1854). Whewell had undermined the purposes of the exhibition. Willis, on the other hand exhibited his apparatus demonstrating the principles of mechanical science, including a new form of Atwood machine which he would soon after present at the Cambridge Philosophical Society (*Proceedings of the Cambridge Philosophical Society* 1 (1843–63): 148).

Did the material aids of education play to the gallery, focusing attention on the object and individual, rather than the fundamental truth to be apprehended? Might different forms of apparatus, however and by whoever streamlined, divert attention to the transitory and material rather than the essential truth? That question was played out in a particular ambivalence expressed by Willis. However simple, childlike, and apparently unmediated his performances, he was unwilling to abandon an association between his name and these material purveyors of mechanical truth.

This is shown in his association with Arthur Rigg, the expert and energetic commercial partner Willis recruited for the mass production, marketing and dissemination of his teaching models. Rigg was a Chester-based Christian educator

and zealot for practical mechanics. Proclaiming that youthful practical training was the key to a better society, Rigg had experimented with his sons, breeding them up as mechanical engineers. He flattered Willis with talk of the excellence of his apparatus and the need for its general adoption:

> If the government but set forth your apparatus as designed to teach not only the Principles of Mechanism but also the construction of Machinery they would do an incalculable service to the cause of industrial pursuits (Arthur Rigg to Robert Willis, 7 April 1856, Add 5136, f 3, Willis Papers, CUL).

Willis responded with models to be copied. Rigg and his sons equipped an extensive workshop to replicate teaching apparatus in quantities sufficient to meet the projected demand of schools and colleges.

The commercial collaboration with Rigg tells us more about the curious identity that Willis assumed in the 1850s: a gentleman, an entrepreneur by proxy, and an uncomfortable expert. One need only think of Cullen and Black, in eighteenth-century Scotland, profiting from chemistry yet anxious to avoid the taint of "projector" (Golinski 1992, 11–49); or Michael Faraday, above the fray of patents, utility and money for its own sake, struggling, nevertheless to ensure personal credit as a philosopher and discoverer (James 1993, 39–40) —to understand that, for a man of science in a commercial world, the attribution of "disinterest" was an achievement. The case of the pedal harp showed that Willis was not above a youthful patent; with the reform of the Post Office in 1840 Willis had exploited the commercial potential of a letter balance. But once established as a philosopher of mechanism in the 1840s he apparently did no more to capitalise on his analytical kinematics, despite the bold claim that it was a route to rapid progress in mechanical invention.

In April 1856, for example, Willis addressed the Society of Arts in London and, before an audience including instrument makers and the distinguished engineer Sir John Rennie, explained the origins and merits of the "improved apparatus for teaching mechanics in schools" which Willis had designed and Rigg would be making (Willis 1856). Willis coyly told his audience that they might "copy and make what use they liked of what he might bring before them", but he wanted "the source" (his name) to continue to be attached to any such borrowings, "trifling though they may be" (Willis 1856). Willis wanted his authorship of the apparatus disseminated and preserved. He insisted to Rigg that labels on exhibited models make it utterly clear that "Prof Willis' was the designer; and when Stokes asked after one item, the Jacksonian Professor advised his former student to go direct to Rigg for "Professor Willis' Iron Tripod Hand" (Willis to Stokes, n.d., W790, Add 7656 (Stokes Papers), CUL). Willis's easy expertise in 1856

also made him prey to men such as Frederick Iliff, an alumnus of Trinity, who wanted approval for "another portion of school apparatus": a single convex lens and appropriate brass work with which to "serve up a Telescope, Microscope, Camera Obscura, & Magic Lantern, with Magic Lantern Microscope" (Frederick Iliff to Willis, 8 April 1856, I3, Add 7656 (Stokes Papers), CUL). For products designed to purvey fundamental mechanical truths —principles which could not be patented— Willis wanted authorial credit.

When the proceedings of the Educational Exhibition of 1854 had come to a close, books, pamphlets, models and apparatus had passed first to the Society of Arts and thence to the Committee of Council on Education. These objects formed the nucleus of a new Educational Collection, a part of the South Kensington Museum administered by the Department of Science and Art. The Educational Collection opened in the summer of 1857 and was effectively publicised by the *Illustrated London News* ("The South Kensington Museum", *Illustrated London News*, 4 July 1857). Willis and Rigg had already been in consultation with the Department of Science and Art (and with counterparts concerned with the advertisement of teaching apparatus through equivalent bodies overseeing education in Ireland). Willis's apparatus was thus given official sanction and credibility by forming part of this Educational Collection.

The Educational Collection of the Museum occupied the central portion of the iron building provided by the Commissioners of the Great Exhibition. Most of the models, diagrams and books it contained were, however, provided by educational suppliers. This trade exhibition thus showed as many as 14,000 visitors a week to see "the most recent, the best, and the cheapest forms of apparatus and the means of imparting knowledge" ("The South Kensington Museum", *Illustrated London News*, 4 July 1857; Chew and Wilson 1993, 96). Willis and Rigg, and the firms of Griffin and of Elliot, were the largest exhibitors in the mechanical section. Their apparatus could be seen alongside the Department's collection of French equipment, a sectional model of a steam-engine by Hughes, microscopes and electrical apparatus. Henslow provided a botanical collection; and there were illustrative teaching cabinets of entomology (the Entomology Society) and mineralogy (Prof Tennant). Waterhouse Hawkins showed teaching models of extinct animals.

Willis's "improved" forms of apparatus for teaching machinery could be seen allying industry and institution at exhibitions through the 1860s until his death (*Newcastle Daily Chronicle*, 27 August 1863; obituary of Willis in *Minutes of Proceedings of the Institution of Civil Engineers* (1874–5), 41: 206–210, on 208). They continued to be used in practical teaching until at least the 1880s. When the astronomer and mathematician Robert Stawell Ball gave up tutoring the sons of the third Earl of Rosse for a chair in applied mathematics and mechanism in the government sponsored Royal College of Science in Dublin, he made

extensive use of a system of experimental apparatus derived from that of Willis. Rigg's company persisted, in London, as Rigg's Technical Education Appliances, Ltd. Boasting medals and recognition from Sydney to New Orleans, Rigg's published extracts of the *Principles of Mechanism* to accompany versions of Willis's models "considered by the Department of Science and Arts to be indispensable for the efficient teaching of … Applied Mechanics" into the 1880s (Willis 1888). This publication —made once the second edition of the *Principles* was out of print— reminds us how closely related were the written and demonstrated mathematics/ mechanics. Other remnants of Willis's apparatus could be found in the Cambridge University Engineering Laboratory, established largely thanks to Alfred Ewing; but they were increasingly regarded as obsolete. It is not without irony that, once Willis's personal skills in construction and demonstration had gone, his successors did not —or could not— appreciate the models which purported to divest machinery of all the extraneous accoutrements of skilled construction. As R. Neville Grenville recalled in 1927, a pilgrimage to the shrine of the man who had taught him in 1868 revealed only that many of these relics were "broken and looked upon as rubbish" (Grenville 1928, 13). When they surfaced briefly in Cambridge in 1936 it was in an exhibition of historic scientific apparatus rather than as exemplars of timeless mechanical principle (Gunther 1937, esp. 88 and 500; for the models" subsequent history see Moon 2003, esp. 219–23).

Conclusion

The sale of Willis's library of 1458 volumes in April 1872 was an admission that further literary work was out of the question (Buchanan 2013, 17). From 1873 the Rev J. C. Williams Ellis deputised for him in the Jacksonian chair (*Cambridge University Reporter*, 9 February and 23 March 1875). Although modern historians celebrate Willis as a "pioneer" of the Engineering Department (Brooke 1985, 204), when he died in 1875 the University's managers commented that only Willis's skills as a lecturer in his Jacksonian chair had allowed a distortion of Jackson's will to continue unquestioned. There were moves to bring the Jacksonian chair "into closer conformity than heretofore" with its original foundation since lectures in mechanism were not to be found there and "ought not to be supplied by rubbing a sponge over the will" (*Cambridge University Reporter*, 16 March 1875). Answers as to what the foundation truly signified ranged through a gamut of disciplines from public health, to chemistry (in its standard or "economic" varieties), sanitary science, or applied physics —the suggestion of Willis's former student, Stokes.

This paper has examined the origins, implementation and aftermath of Willis's systematic view of the science of mechanism in the second and third quar-

ters of the nineteenth century. In early life, Willis had toyed with practical mechanics in London, learned mechanical science in Cambridge, and served as in-house experimental demonstrator at meetings of the Cambridge Philosophical Society. As Jacksonian professor in Cambridge from 1837, as a key player in the British Association, and, eventually, as expert advisor to government, Willis promoted a systematic understanding of mechanism, mechanics and machinery.

He did that partly by promoting the mathematical conceptions crystallized in his book *Principles of Mechanism* (1841) (Marsden 2004). But, as this paper has shown, Willis's conceptions of mechanism, mechanics, and machinery also had a performative dimension, involving elaborate demonstration lectures with apparatus designed to portray practical mechanics as reducible to simple mathematically comprehensible components. Willis had collaborated with William Whewell to exhibit the science of mechanism to Cambridge students, in an attempt to make it an adjunct to a liberal education, and to disseminate it to the new college-trained professional engineers beyond Cambridge but, they believed, in need of pedagogic guidance. Whilst Whewell effectively withdraw from this arena, in the 1850s Willis extended, embodied, commercialized and institutionalized his programme of mechanical inculcation. In Willis's work there was, then, a symbiosis of theoretical, and written, elements and practical, or performative, staging. This paper has focused on the latter, in order to offer an enriched account of the cultural apparatus of mechanism in mid-Victorian Britain.

Acknowledgements

For permission to quote from manuscripts I am grateful to the British Library, the Syndics of Cambridge University Library, and the University of St Andrews.

Notes

1. Add. 5143, Willis Papers, Cambridge University Library (hereafter CUL).
2. The project, culminating in British patent no. 4343 (13 February 1819), is meticulously described in Willis's private diary (21 October 1819 to 21 January 1821), Add. 7574, Willis Papers, CUL. By May 1820 Willis had spent approximately £500 on developing and protecting his harp.
3. Herschel's machine allegedly solved certain transcendental equations.
4. There is an odontograph made by Holtzapffel in the National Museum of Science and Industry, London (catalogue 1980: 1131).
5. Willis's disqualifications relate, in part, to his failure to deliver on promises consistent with the BAAS's national objects once distracted by the history of architecture.
6. Willis was President of Section G in 1839, 1842 and again in 1863.
7. See Willis's Certificate of Election, Library of the Institution of Civil Engineers.

8. Willis lists “The classification of the machinery in the classified lists of the Great Exhibition of 1851” at the back of Willis (1870) but the reference there points to his report on Class VI.
9. Yoshida suggests that Willis wrote The Industry of Nations but it does not appear in Willis’s careful listings of his “literary and scientific works”, including Great Exhibition reports: see Willis (1870), endpapers, for one such list. The author was probably Charles Tomlinson, who had written since the 1830s on the useful arts for the SPCK. I am grateful to Aileen Fyfe for this suggestion.

Reference list

Airy, George Biddell. 1825. On the Forms of the Teeth of Wheels. *Transactions of the Cambridge Philosophical Society*, 2: 277–86.

Becher, H. W. 1995. Radicals, Whigs and Conservatives. The Middle and Lower Classes in the Analytical Revolution at Cambridge in the Age of Aristocracy. *British Journal for the History of Science*, 28: 405–26.

Brooke, Christopher. 1985. *A History of Gonville and Caius College*. Woodbridge: Boydell Press.

Buchanan, Alexandrina. 2013. *Robert Willis (1800–1875) and the Foundation of Architectural History*. Woodbridge: Boydell Press.

Cannon, Susan Faye. 1978. *Science in Culture. The Early Victorian Period*. New York and Folkestone: Science History Publications.

Cartwright, David Edgar. 1999. *Tides. A Scientific History*. Cambridge: Cambridge University Press.

Chambers, T. G. 1896. *Register of the Associates and Old Students of the Royal College of Chemistry, the Royal School of Mines, and the Royal College of Science; with Historical Introduction and Biographical Notices and Portraits of Past and Present Professors*. London: Hazell.

Chew, Kenneth and Anthony Wilson. 1993. *Victorian Science and Engineering Portrayed in the Illustrated London News*. Stroud: Allan Sutton.

Clark, John Willis. 1889–92.The Foundation and Early Years of the Society. *Proceedings of the Cambridge Philosophical Society*, 7: i–xlviii.

Dawes, Richard. 1854. *Teaching of Common Things*. London: Groombridge and Sons.

Eales, Richard. 1985. *Chess: The History of a Game*. London: Batsford.

Emmerson, George S. 1973. *Engineering Education. A Social History*. Newton Abbot: David & Charles.

Francis, H. T. 1923. *In Memoriam. John Venn*. Cambridge: Cambridge University Press.

Golinski, Jan. 1992. *Science as Public Culture. Chemistry and Enlightenment in Britain, 1760–1820*. Cambridge: Cambridge University Press.

Great Exhibition. 1852. Appendix B. Instructions from the Council of Chairmen to the Juries. In *Exhibition of the Works of Industry of All Nations, 1851. Reports by the Juries on the Subjects in the Thirty Classes into which the Exhibition was Divided*, xxiii–xxiv. London: Printed for the Royal Commission by William Clowes and Sons.

Grenville, R. Neville. 1928. The Birth of Engineering at the University of Cambridge. *Cambridge University Engineers and Aeronautical Societies" Journal*, 3: 13–20.

Gunther, R. A. 1937. *Early Science in Cambridge*. Oxford: Oxford University Press.

Hartenberg, Richard S. and Jacques Denavit. 1964. *Kinematic Synthesis of Linkages*. New York: McGraw-Hill.

Hilken, T. J. N. 1969. *Engineering at Cambridge University 1783–1965*. Cambridge: Cambridge University Press.

Holtzapffel & Co. 1838. *A List of Scales of Equal Parts, Applicable to Various Purposes of Engineering, Architectural and General Science*. London: John Weale.

Holtzapffel & Co. 1849. *Holtzapffel & Co…Engine, Lathe, & Tool Manufacturers*. Trade catalogue. London: Holtzapffel.

Holtzapffel, Charles. 1846–50. *Turning and MechanicalManipulation*. 3 vols. London: Holtzapffel.

James, Frank A. J. L. ed. 1993. *The Correspondence of Michael Faraday. Volume 2. 1832-December 1840*. London: Institution of Electrical Engineers.

Marsden, Ben. 1992. Engineering Science in Glasgow. Economy, Efficiency and Measurement as Prime Movers in the Differentiation of an Academic Discipline. *British Journal for the History of Science*, 25: 319–46.

Marsden, Ben. 1998. "A Most Important Trespass". Lewis Gordon and the Glasgow Chair of Civil Engineering and Mechanics, 1840–1855. In *Making Space for Science. Territorial Themes in the Shaping of Knowledge*, edited by Crosbie Smith and Jon Agar, 87–117. Basingstoke: Macmillan.

Marsden, Ben. 2004. "The Progeny of These Two 'Fellows'". Robert Willis, William Whewell and the Sciences of Mechanics, Mechanics and Machinery in Early Victorian Britain. *British Journal for the History of Science*, 37: 401–34.

Mertens, Joost. 2000. From Tubal Cain to Faraday. William Whewell as a Philosopher of Technology. *History of Science*, xxxviii: 321–42.

Moon, Francis C. 2003. Robert Willis and Franz Reuleaux. Pioneers in the Theory of Machines. *Notes and Records of the Royal Society of London*, 57: 209–30.

Morrell, Jack and Arnold Thackray. 1981. *Gentlemen of Science. Early Years of the British Association for the Advancement of Science*. Oxford: Clarendon Press.

Morrell Jack and Arnold Thackray. eds. 1984. *Gentlemen of Science. Early Correspondence of the British Association for the Advancement of Science*. London: Royal Historical Society.

Morus, Iwan Rhys. 1991. Correlation and Control. William Robert Grove and the Construction of a New Philosophy of Scientific Reform. *Studies in History and Philosophy of Science*, 22: 589–621.

Morus, Iwan Rhys. 1992. Different Experimental Lives. Michael Faraday and William Sturgeon. *History of Science*, 30: 1–28.

Morus, Iwan Rhys. 1996. Manufacturing Nature. Science, Technology and Victorian Consumer Culture. *British Journal for the History of Science*, 29: 403–34.

Reeks, Margaret. 1920. *Register of the Associates and Old Students of the Royal School of Mines and History of the Royal School of Mines*. London: Royal School of Mines.

Rennie, George. ed. 1841. *Practical Essays on Millwork and Other Machinery*. London: John Weale.

Robson, R. and Walter F. Cannon. 1964. William Whewell, F.R.S. *Notes and Records of the Royal Society*, 19: 168–91.

Shapin, Steven. 1989. The Invisible Technician. *American Scientist*, 77: 554–63.

Sidney, Edwin. 1854. *Teaching the Idiot. A Lecture, delivered in St. Martin's Hall, London, August 4, 1854, in Connection with the Educational Exhibition of the Society of Arts, Manufactures, and Commerce*. London: Routledge.

Sopwith, T. 1841. *Description of Geological Models, Illustrating the Nature of Stratification*. Newcastle: For the Author.

Todhunter, I. 1876. *William Whewell, D.D., Master of Trinity College Cambridge. An Account of His Writings with Selections from his Literary and Scientific Correspondence*. 2 vols. London: Macmillan.

Ure, Andrew. 1835. *The Philosophy of Manufactures*. London: Charles Knight.

Standage, Tom. 2002. *The Mechanical Turk. The True Story of the Chess-Playing Machine That Fooled the World*. London: Allen Lane.

Whewell, William. 1854. *On the Material Aids of Education. Being an Inaugural Lecture on the Occasion of the Educational Exhibition of 1854*. London: John W. Parker and Son.

Willis, Robert. 1837. On the Teeth of Wheels. *BAAS Report*, 7: 135.

Willis, Robert. 1838a. On the Teeth of Wheels. *Transactions of the Institution of Civil Engineers*, 2: 89–112.

Willis, Robert. 1838b. On the Odontograph. *BAAS Report*, 8: 154.

Willis, Robert. 1839. *Syllabus of a Course of Experimental Lectures on the Principles of Mechanism*. Cambridge: J. and J. J. Deighton.

Willis, Robert. 1840. *Syllabus of a Course of Experimental Lectures on the Principles of Mechanism*. Cambridge: J. and J. J. Deighton.

Willis, Robert. 1841. *Principles of Mechanism*. Cambridge: J. and J. J. Deighton.

Willis, Robert. 1842a. On Gothic Tracery, exemplified by the Windows of the Chapter House at Salisbury. *Civil Engineer and Architect's Journal*, 5: 204.

Willis, Robert. 1842b. Description of the Cymagraph for Copying Mouldings. *Civil Engineer and Architect's Journal*, 5: 219–20.

Willis, Robert. 1851. *A System of Apparatus for the Use of Lecturers and Experimenters in Mechanical Philosophy*. London: John Weale.

Willis, Robert. 1852a. Class VI. Report on Manufacturing Machines and Tools. In *Exhibition of the Works of Industry of All Nations, 1851. Reports by the Juries on the Subjects in the Thirty Classes into which the Exhibition was Divided*, 194–205. London: Printed for the Royal Commission by William Clowes and Sons.

Willis, Robert. 1852b. Machines and Tools for Working in Metal, Wood, and Other Materials. In *Lectures on the Results of the Great Exhibition of 1851 Delivered Before the Society of Arts, Manufactures, and Commerce, at the Suggestion of H. R. H. Prince Albert, President of the Society*, 291–320. London: David Bogue.

Willis, Robert. 1856. On Improved Apparatus for Teaching Mechanics in Schools. *Journal of the Society of Arts*, 4: 344–46.

Willis, Robert. 1862. [Presidential] Address, *BAAS Report*, 32: li–lxi.
Willis, Robert. 1870. *Principles of Mechanism*. 2nd ed. London: Longmans, Green.
Willis, Robert. 1888. *Extracts from the Second Edition of Principles of Mechanism*. London: Rigg's Technical Education Appliances.
Woodbury, Robert S. 1958. *History of the Gear-Cutting Machine*. Cambridge, MA: MIT.
Yapp, G. W. ed. 1854. *Official Catalogue of the Educational Exhibition, held in St Martin's Hall, July 4, 1854*. London: W. Clowes and Sons..
Yeo, Richard. 1993. *Defining Science. William Whewell, Natural Knowledge, and Public Debate in Early Victorian Britain*. Cambridge: Cambridge University Press.
Yoshida, Fumikazu. 1983a. *The Industry of Nations* and Marx's *Das Capital*. *Historia Scientiarum*, 24: 77–85.
Yoshida, Fumikazu, 1983b. Robert Willis' Theory of Mechanism and Karl Marx. *Historia Scientiarum*, 25: 87–92.

Willis, speech, sound, and music

Robin Maconie

Some years ago, the return appearance of a distinguished special guest on *The Simpsons* prompted me to inquire of a philosopher acquaintance whether the voice of Stephen Hawking could be said to be his own voice, and if not, whose voice would it be. Professor Hawking has lately moved to claim the American accented speech synthesizer as his personal voice, by declining the offer of an upgrade, in a press release observing, no doubt tongue in cheek, that the public would no longer recognize the change of voice as himself.

Music occupies a crucial place in the history of western science as a medium of inquiry into vibrating systems and the science of voice recognition. Political and social revolution in the late eighteenth century provoked intellectual interest in the origins of language and uncovering the basic units of primordial speech that indicate character, social status, and regional identity. By tradition 'having a voice' determines who you are and whether you are heard, whatever you might have to say. In the theatre of Shaw's *Pygmalion*, quality of speech is linked to intellectual status, and pronunciation and vocabulary are tokens of social status. Robert Willis's papers on vowel production are a contribution to understanding how speech may actually work, from a time when the way to achieve understanding was by creating mechanical models.

Willis is remembered in the history of mechanical science for having figured out at an early age that a popular exhibit by Viennese inventor Wolfgang von Kempelen, purporting to be a chess-playing artificial intelligence, was almost certainly operated by a real person concealed inside the cabinet or Chinese box (Tufte 1997, 66–67), Figure 1. However his greater achievement by far, I be-

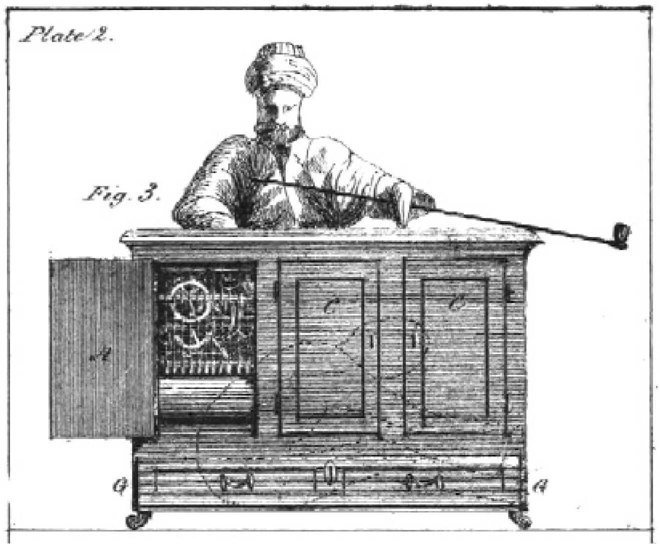


Figure 1
The Automaton Chess Player by Wolfgang von Kempelen. Willis demonstration that a man could be hidden inside —profile in dotted line (Willis 1821)

lieve, is the potential contribution of Willis's papers on vowel sounds to the improvement in design of Kempelen's makeshift but nonetheless successful 1791 proof of concept of a machine for synthesizing speech (Fig. 2), an authentic working precursor of Professor Hawking's speech synthesizer.

Vowels are the resonances of speech. In music, vowels carry the song and associated emotion. Willis's proposal of a more efficient mechanism for synthesizing vowels and modulating between vowels employs a valve mechanism to control the resonance process more exactly, and execute transitions from vowel to vowel in a more natural manner. Willis's papers are referenced in Hermann Helmholtz's magisterial survey *On the Sensations of Tone*, the combination of free reed and tube resonator endorsed as a practical solution for the 'audition' (i.e., synthesis) of vowel sounds (Helmholtz 1885, 117–18). The several contributions of Kempelen, Kratzenstein, and Willis to speech science are examined by Charles Wheatstone in a review published in 1837, the year Willis was appointed to the Jacksonian Professorship. In preparing his review, Wheatstone constructed his own working model, with improvements, of Kempelen's machine. (Wheatstone 1879, 348–67)

In the history of western science, issues of speech recognition and synthesis are invariably and traditionally musical in implication. The ancient Greeks as-

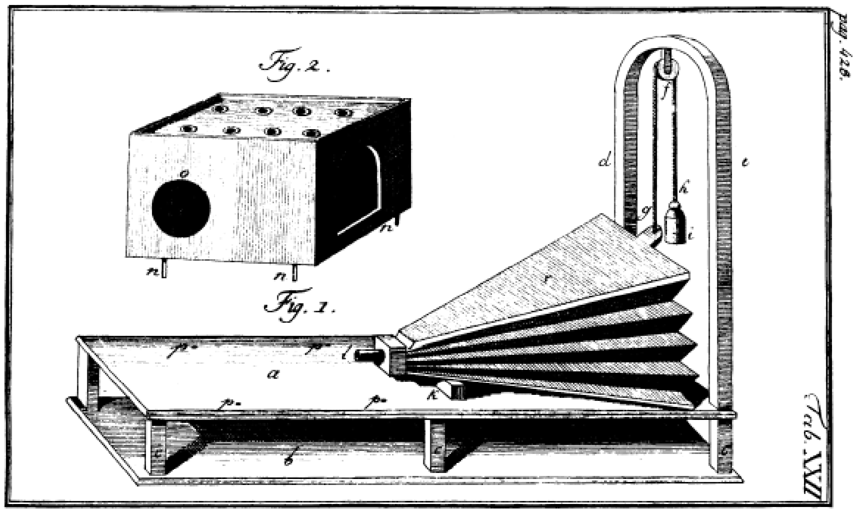


Figure 2
Von Kempelen speaking machine (Kempelen 1791)

signed character traits to different modes or systems of tuning, called *temperaments.* Medieval clerics wrestled over many generations to develop a system of accents and graphic additions to preserve the authorized intonation of a sacred text. The resulting diacriticals or pronunciation guides, called *neumata*, evolved into music notation as we know it today, while continuing to serve in their original function as punctuation marks.

Among intellectuals in the late eighteenth century, absence of speech had become a defining ingredient in a new and divisive debate over whether the great apes, including the benign but speechless orang-utan, were capable of reasoning and deserved to be treated as members of the human family. In the public mind, the argument extended to questioning the intellectual status of non-European humanity. Sir Oran Haut-ton, the fictional hero of *Melincourt*, a popular novel by Thomas Love Peacock published in 1817, inherits a baronetcy and becomes a much-loved Member of Parliament, despite having nothing to say. (Michell 1984, 97–106)

The art of inferring a human presence, condition, and characteristic speech of an individual or group, from the physical structures they inhabit, embraced human psychology and anatomy as well as a knowledge of acoustics. From measurements and plan drawings of the bony structures of the face, Dutch anatomist Petrus Camper concluded that the orang-utan was mute, not because it lacked intelligence, but because the design of its jaw and mouth parts made it incapable of forming

words. Such conclusions in revolutionary times had political implications, arguing that fellow human beings who for whatever reason were unable to speak for themselves, were still capable of establishing functioning communities. The enigma of mute intelligence has since been addressed in more recent times by Alan Turing and the Turing Test, aiming to decide whether the unseen partner in a dialogue, or even a Cambridge professor of astrophysics, is a human being or a machine. In music we recognize John Cage and his silent composition *4' 33"* invoking the composer's right to silence in the court of Senator Joe McCarthy.

Composers Mozart, Beethoven, Clementi and Haydn were actively involved or implicated in processing music for mechanical reproduction. In 1779 the Imperial Academy of Sciences at St. Petersburg offered a prize for designing a mechanism for reproducing vowel sounds, for use as a *vox humana* organ stop for imitating a wordless singing voice. The prize was won by Count Christian Gottlieb Kratzenstein, inventor of a set of organ pipes of varying fixed shapes, one for each vowel. While meeting the strict terms of the contest, Kratzenstein's invention was unsuitable for incorporating in a pipe organ, since it would have involved creating a separate register for each vowel, an expensive addition still leaving the problem of liaison between vowels unsolved. In 1791, Kempelen unveiled the third version of his prototype speech synthesizer, a programmable assembly of modules for reproducing speech in virtually any language by emulating the physical actions and structures of the vocal tract: the lungs by bellows, vocal cords by free reeds, and consonants by ancillary percussion. The device or contraption incorporated a flexible leather mouthpiece allowing the vowel to be squeezed into shape like a klaxon, a mechanism capable in principle of adapting to the control of a swell pedal or lever action at an organ keyboard. (Beyer 1999, 12–13)

Kempelen had been inspired technically by French inventor Jacques de Vaucanson's celebrated exhibit of a mechanical duck capable of expressing itself at both ends of the alimentary canal. Philosophically, Kempelen was determined to challenge the prevailing aristocratic conceit that the faculty of speech was a divine gift, by exposing it as a byproduct of human engineering, having begun working on the project in 1769. According to Manfred Schroeder, Willis's special contribution to speech synthesis was his discovery that vowel quality depended only on the length of the resonating tube, and not on its shape or width. (Schroeder 2004, 24–27)

Willis's contribution to speech synthesis came at a time of innovation in the manufacture of musical instruments, in particular brass and woodwinds. Improved rotary and piston valves enabled composers to indulge in a new music of changing key and emotional volatility, allowing audiences to judge, from their fluency of tone and smoothness of articulation, how efficiently the new mecha-

nisms functioned as switchable conduits for compressed air. The musical success of these programmable airways would pave the way for the installation of efficient systems for the supply of fresh water and safe disposal of waste water, and in London even for the transportation of people and the mail by underground tube, an idea just now attracting attention in the United States.

By 1800, android fever had excited a popular market of do it yourself parlour games or kits for composing melodies by the throw of a pair of dice, promoted under the name of 'country-dances' —a euphemism for peasant or gipsy entertainments— or 'waltzes' after the German term for a barrel or lucky dip. In Britain, Kempelen's speaking machine attracted the attention of Willis in Cambridge, and in London Charles Wheatstone, the ingenious nephew of an established musical instrument maker and publisher in1806 of an English edition of a 'Musical Dice Game' attributed to Mozart. (Prieberg 1960, 113–18)

In February 1828, at the Royal Institution, London, Michael Faraday presented a paper 'On the Resonances, or Reciprocated Vibrations of Columns of Air' on Wheatstone's behalf. (Wheatstone, 36–63) The paper addressed the use of passive air columns as resonators to amplify exotic musical instruments, examples including a jew's harp, a Javanese metal keyboard or *génder*, and Chinese mouth organ or *sheng*, the lastnamed a bundle of bamboo pipes protruding from a cup-shaped mouthpiece. With the aid of a simple sliding tube, moving in and out like a Swanee whistle, Wheatstone succeeded in exciting sympathetic resonances at frequencies higher than the continuous tone of a tuning fork, a seeming impossibility, since the sound of a tuning fork has no overtones. (Pesic 2014, 195–209. *Note*: Pesic's account of Wheatstone nowhere alludes to Willis, nor does Helmholtz mention Wheatstone, other than footnotes added by translator Alexander J. Ellis.)

In April 1828, just a few months later, Willis presented the first of two papers 'On Vowel Sounds' to the Cambridge Philosophical Society, examining the potential of a sliding tube resonator for reproducing and studying vowel sounds. In modelling the speaking voice as a dynamical system for the disposal of excess energy through a system of relays, Willis was following in the footsteps of Ctesibius, the engineer of pre-Roman times whose invention of a compressed air heating system the *hydraulis*, would be destined to evolve into the keyboard pipe organ of J. S. Bach. That Willis approached the synthesis of speech as a problem in fluid mechanics, or even drainage, has less to do with a prior interest in music, I suspect, than reflect a typically Cambridge approach to problem solving, related to geographical location.

Their paths having converged in 1837, the pair went their separate ways. Wheatstone would go on to collaborate with Charles Babbage on the design of intricate switching mechanisms before devoting himself to the manufacture of a

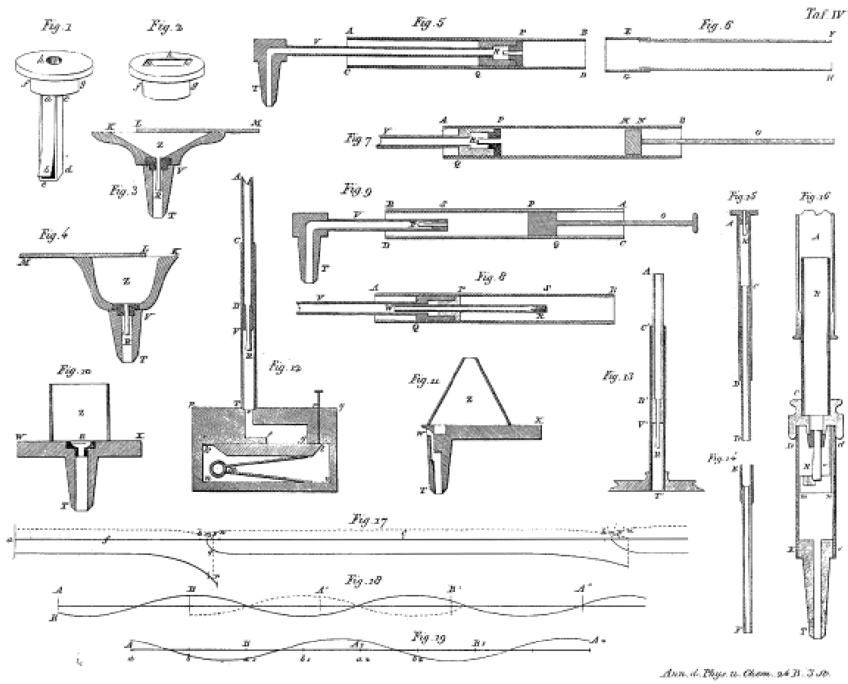


Figure 3
Plate from “On the Vowel Sounds, and on Reed Organ-Pipes” (Willis 1832)

popular new range of musical instruments powered by compressed air: the mouth organ, button concertina, keyboard accordion, and domestic harmonium, instruments of a new nineteenth-century aesthetic of emotional expression. Willis however appears to have abandoned work on an improved speaking machine to focus on the structural analysis of late medieval cathedrals and churches. A miniaturized version of the sliding tube mechanism became a key component of the popular *serinette* or mechanical chirping bird. Stravinsky reproduces the exact musical figures of artificial birdsong in flute parts for the ‘Dawn Chorus’ sequence of *The Rite of Spring*, at rehearsal number [11] of the score.

Whether or not he was influenced against challenging the Almighty by contributing to a machine capable of speech, and thus possessed of a soul, Willis’s lifetime achievement in reading the shapes and voids of the medieval stonemason’s art is all the same a natural extension of Petrus Camper’s detective work in assessing the intelligence of our not so recent ancestors from the physical structures they inhabit. Hints of the forces at play emerge in the writings of Willis’s younger contemporary Samuel Butler, a graduate of St. John’s who elected to

withdraw from what he described as the claustrophobia of College life to a smallholding in the southern highlands of New Zealand, there to pass the time corresponding with Charles Darwin on the origin of species by day, while meditating on the future of machine intelligence by night. In his novel *Erewhon*, set in New Zealand, Butler muses ‘It must have seemed highly improbable that machines should learn to make their wants known by sound, even through the ears of man; may we not conceive then, that a day will come when those ears will be no longer needed —when its language shall have been developed from the cry of animals to a speech as intricate as our own?’ (Butler 1872, 237)

From where I sit, Willis is a person of interest in two very different ways. One, Willis’s association by appointment with Isaac Milner, a key figure in the establishment of a permanent British colony in the North Island of New Zealand, and two, his contribution as engineer to the science of artificial speech, and by association, to the development of electronic music in the twentieth century.

Interpreting the intentions behind the unfamiliar speech of alien species of humanity was a concern for the patrons and backers of James Cook’s voyages to the Pacific in search of a Great Southern Continent. Elders of the Royal Society exchanged memoranda on what to expect, and strategies to employ. Lord Monboddo, a friend of Samuel Johnson, produced a summary of the universal features, accents, and redundancies of speech and song of remote oral cultures. When Cook famously ordered the ship’s piper to entertain a royal welcoming party on the beach at Otaheite, a gesture puzzling to some historians, I suspect the Captain was acting on Monboddo’s good advice. Graphic notations for mapping the contours of rhetorical speech, including an account of Hamlet’s soliloquy delivered in the high style of actor David Garrick, were devised by Joshua Steele in a communiqué published under the title *Prosodia Rationalis*, Figure 4.

From his London lodging, Benjamin Franklin volunteered an extended alphabet with additional letter forms for the culturally unbiased transcription of alien speech. A visit to London by the child prodigy Mozart in 1764 provided the opportunity for an examination by Daines Barrington for the Royal Society. The boy was asked to improvise mock arias and accompaniments in the flamboyant style of Italian opera, expressing a range of archetypal emotions, which his father Leopold took down in manuscript. (Barrington 1770, 54–64) Such a register of childish emotions, untempered by adult civilization, were apt to assist, like Hogarth’s studies of facial expression, in the interpretation of emotional temper and peaceful or aggressive intentions of alien and potentially uncivilized peoples. Barrington’s convention of recording archetypal emotions in song form is followed by Thomas Kendall (1820), and James Arthur Davies (1854), formerly of Trinity College, in their early studies of Maori speech.

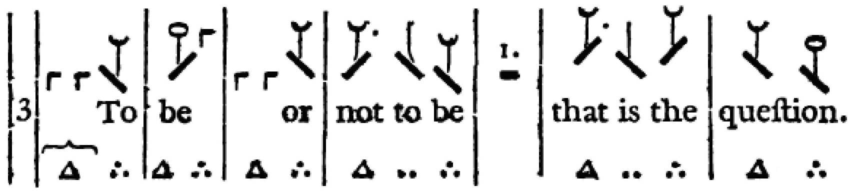


Figure 4
Musical transcription of Hamlet's soliloquy as spoken by David Garrick (Steele 1779)

In the aftermath of Cook's voyages of exploration, images of Pacific culture, music, and dance rapidly propagated across Europe and are referenced in art and literature. We recognize Papageno the birdcatcher and Papagena, spirit entities in Mozart's opera *The Magic Flute*, as images of native New Zealanders living in harmony with nature, dressed in feathered cloaks and wearing feathers in their hair. (Maconie 2010)

An admirer of Johann Kaspar Lavater, the Swiss pioneer of character analysis by facial expression, younger brother of evangelist Joseph Milner, and mentor of William Wilberforce, Jacksonian Professor Isaac Milner applied his talents as a mathematician and chemist to the science of rhetoric as an occult force, a species of action at a distance comparable with electricity and Newtonian gravity, to be newly employed for converting the heathen. In 1811 Milner, Wilberforce, and James Boswell nominated Samuel Marsden and Thomas Kendall to establish a settlement in the North Island under the protection of friendly Maori. Kendall interpreted his task of transcribing the native speech as scientific in nature, after the example of Joseph Banks, and developed an elaborate system of diacriticals to convey fine nuances of speech. Marsden, displeased, accused Kendall of going native, and sought his dismissal. In 1820 Kendall returned to Cambridge to plead his case accompanied by chief Hongi Hika, his pronunciation advisor and collaborator, and Hongi's cousin Hohaia Waikato. Kendall's revised wordlist and pronunciation guide was reviewed and passed for publication by the young Professor Samuel Lee. The party was received at court by King George IV, the normally taciturn chief advancing hand outstretched with the words 'How do you do, Mr. King George?' to which the delighted monarch responded,'And how do *you* do, Mr. King Hongi?' —an exchange immortalized in the urban legend of King Kong, since reclaimed for New Zealand by moviemaker Sir Peter Jackson. (Maconie, 2012)

Willis's place in the history of music technology emerges from reading Helmholtz and Dayton Clarence Miller on the science of voice recording and recognition, covert intelligence research resumed with new urgency in the Cold War era

of the 1950s. Stockhausen's *Electronic Studies I* and *II*, composed in 1953 and 1954, are the young composer's first major exercises in compound tone synthesis —in effect, synthesized speech sounds— executed in the new medium of magnetic tape. (Both studies are posted on YouTube.) The crystalline tones of *Study I* call to mind a pleasantly jingling luxury Victorian era musical box. In *Study II*, note collections are combined in an echo chamber as if in a blender, in an attempt to create composite resonances, sounding at times like a barrel organ or paper-roll harmonium. I was curious to know why two such early studies are so different in sound, and opposed in procedure: they are in fact, mutually contradictory. The conceptual difference between a musical box and a squeeze box is a key paradigm shift from a classical view of speech as retrieving words in order from a database, to a nineteenth-century engineering concept of speech as a process. Stockhausen is following Willis's innovation in speech synthesis in the early 1800s transforming the working model of a speaking machine from the classical musical box using words for notes represented by Joseph Fourier, to the Kempelen and Willis goal of imitating the production line mechanism of speech itself.

Thirty years after Stockhausen's electronic studies, the Turing Test of artificial intelligence is revisited in the computer cadenzas of Pierre Boulez's *Répons* (1981–84), an artificial intelligence in apparently spontaneous dialogue with six keyboard soloists in a cocktail party effect calling to mind the chiming clocks of Ravel's *L'Heure Espagnole*. The speech science objectives of new music are not merely coincidental, they are essential goals of western music at the highest level, for a thousand years. Boulez's speech science goals, for example in the work *Anthèmes II* (1997), a sonata for solo violin in dialogue with a computer, are to all intents and purposes identical —one might even say, *contemporary*— with medieval settings of 'Viderunt omnes' and Sederunt principes', slow-motion studies in magnified voice resonance composed in twelfth-century Paris by Perotinus the Great.

Reference list

Barrington, Daines. 1770. "Account of a Very Remarkable Young Musician. In a Letter from the Honourable Daines Barrington, F.R.S. To Mathew Maty, M. D. Sec. R.S". *Philosophical Transactions* 60: 54–64.

Beyer, Robert T. 1999. *Sounds of Our Times: Two Hundred Years of Acoustics*. New York: AIP/Springer Verlag.

Butler, Samuel. 1969. *Erewhon: or Over the Range*. London: Heron Books. (Facsimile edition London: Trübner, 1872).

Davies, James Arthur. 1854. *On the Native Songs of New Zealand*. London: Woodfall and Kinder. (The same, incorporated as an Appendix in Sir George Grey, *Polynesian My-*

thology and Ancient Traditional History of the New Zealanders. London: Trübner, 1855).

Helmholtz, Hermann. 1954. *On the Sensations of Tone: As a Physiological Basis for the Theory of Music.* New York: Dover. (Reprint of the Second English edition tr. ed. Alexander J. Ellis, 1885).

Kempelen, Wolfgang von. 1791. *Le mécanisme de la parole, suivi de la description d'une machine parlante*. Vienne: B. Bauer.

Kendall, Thomas, and Samuel Lee. 1820. *A Grammar and Vocabulary of the Language of New Zealand.* London: Church Missionary Society.

Maconie, Robin. 2010. "On the prehistory of music in New Zealand". *Musical Times* 151 (No. 1910, Spring 2010): 23–30.

—. 2012. "The Search for King Kong". In *Avant Garde: An American Odyssey from Gertrude Stein to Pierre Boulez.* Lanham MD: Scarecrow Press, 1–25.

Michell, John. 1984. *Eccentric Lives and Peculiar Notions*. London: Thames and Hudson.

Mozart, Wolfgang Amadé. 2005. *London Sketchbook – London Notebook* ed. Hans-Udo Kruels. Wellington NZ: Artaria Editions.

Pesic, Peter. 2014. *Music and the Making of Modern Science*. Cambridge MA: MIT Press.

Prieberg, Fred K. 1960. *Musica ex Machina: Über das Verhaltnis von Musik und Technik.* Berlin: Ullstein Verlag.

Schroeder, Manfred. 2004. *Computer Speech: Recognition, Compression, Synthesis*. Second edition. New York: Springer Verlag.

Steele, Joshua. 1779. *Prosodia Rationalis*. London: Nichols. (Facsimile reprint of the second edition. Hildesheim: Georg Olms Verlag, 1971.)

Tufte, Edward R. 1997. *Visual Explanations: Images and Quantities, Evidence and Narrative.* Cheshire CT: Graphics Press.

Wheatstone, Charles. 1879. *The Scientific Papers of Sir Charles Wheatstone*. London: Taylor and Francis. (Reprinted Cambridge University Press, 2011.)

Willis, Robert. 1821. *An attempt to Analyse the Automaton Chess Player* . London: Booth.

—. 1830. "On the pressure produced on a flat plate when opposed to a stream of air issuing from an orifice in a plane surface". *Transactions of the Cambridge Philosophical Society* 3: 129–40.

—. 1830. "On the vowel sounds". *Transactions of the Cambridge Philosophical Society* 3: 231–68.

—. 1832. "Über Vocaltöne und Zungenpfeifen". *Annalen der Physik und Chemie*, 2nd ser. 24: 397–437

Awful Grandeur and Deceptive Artifices. Robert Willis and Ancient Egyptian Architecture

Chris Elliott

We can never know for certain what Robert Willis's projected history of architecture would have said on the subject of Ancient Egypt, but the material deposited in Cambridge University Library by his nephew and literary executor John Willis Clark allows us to gain at least some insight into his sources of information, his analysis of this information, and the nature of his views on Pharaonic Egyptian architecture.

There seems to be relatively little material on this topic in the archive, although more may in due course emerge from missing and dispersed material, and there may be tangential or passing references in material on other topics. What there is has been found in four folders. One (CUL ADD MS 5031) deals with Ancient Monuments, a second (5032) contains material on Egypt and its architecture, a third (5130) contains material on the history of the arch, and the fourth (5135) has draft lecture notes, probably related to a series of lectures on the history of architecture given by Willis to the Royal Institution in 1846 and 1847.[1]

Sources and Context

Before considering what Willis had to say about Ancient Egypt and its architecture, it is important to consider his sources of information, and the general state of knowledge on this topic in his era. Both Sebastiano Serlio (1540, Book III) and Johann Bernhard Fischer von Erlach (1721) had included material on Ancient Egypt in their highly influential publications on architecture, but their focus was on sites and structures described in Classical sources, and on sites in the vi-

cinity of Cairo, particularly the pyramids of Giza, as well as in Serlio's case the Ancient Egyptian obelisks in Rome. Few European travellers penetrated further south, where the best preserved Egyptian temples could be found at sites such as Dendera, Karnak, Luxor, Kom Ombo, and Philae.

Willis was born in 1800, during the course of the Napoleonic expedition to Egypt and its defeat by British forces, and grew up in an era that saw the birth of modern Egyptology. The official report of the Commission on the Sciences and Arts, which had accompanied French troops to Egypt, appeared between 1809 and 1828, and included much material on the surviving monuments of Ancient Egypt (Gillispie and Dewachter 1997). More influential, since it was available earlier, in translation into a number of European languages, and in a variety of formats, was the work of one of the Commission's members, Vivant Denon (1747–1825),[2] which described and illustrated Egyptian temples and architectural elements such as column capitals. (Denon 1807; Elliott 2012 15–17).

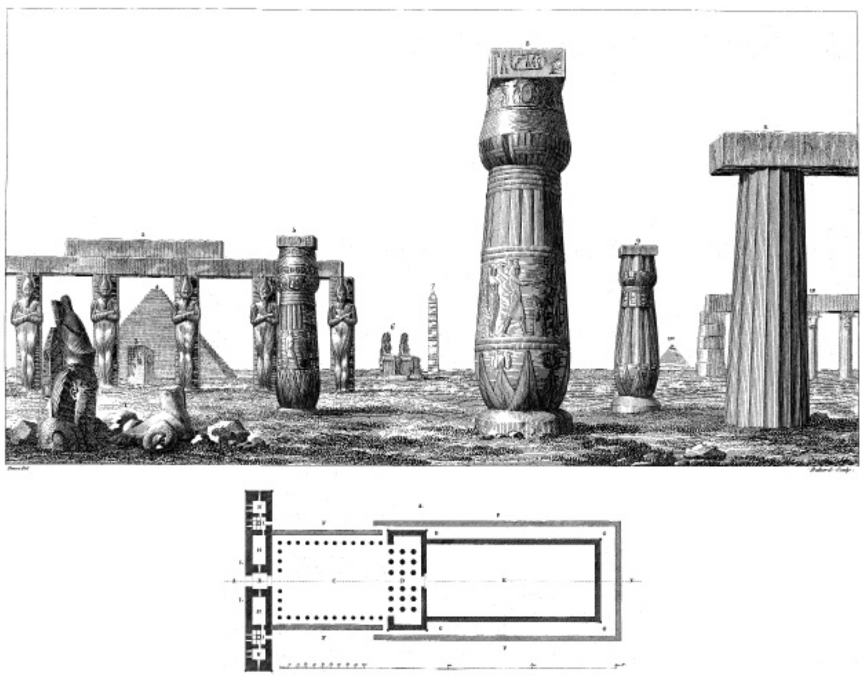


Figure 1
Capriccio of Egyptian architectural fragments and plan of temple from Denon's *Voyage dans la Basse et la Haute Égypte*[3]

From 1822 onwards, the work of Jean-François Champollion (1790–1832)[4] allowed the reading of Egyptian hieroglyphic texts, and the beginning of the recovery of information from these texts on the chronology and history of Pharaonic and Ptolemaic Egypt (Elliott 2012, 75–83; Ray 2007; Solé and Valbelle 2002). The first half of the nineteenth century also saw a series of privately and state funded archaeological expeditions to Egypt, which carried out extensive excavations and epigraphy, often over an extended period of time. Sir John Gardner Wilkinson (1797–1875)[5] worked in Egypt 1821–33, Champollion, accompanied by the Italian Ippolito Rosellini (1800–1843),[6] was there 1828–9, Robert Hay (1799–1863)[7] 1824–8 and 1829–34, and the Prussian Richard Lepsius (1810–1884)[8] 1842–5. All of these, with the exception of Hay, produced important publications which were highly influential.

The main sources cited by Willis in his papers are, with the exception of Hay, precisely those just mentioned; Wilkinson, Rosellini, and Lepsius. Additionally, he mentions (in connection with Petra) the views of David Roberts (1796–1864)[9] (CUL MS Add. 5031: 1) the record of his travels in the Levant (including Egypt) by Sir William Wilde[10] (CUL MS Add 5031: 10), and the account of his travels and excavations in Egypt by Giovanni Belzoni[11] (CUL MS Add 5032: 199).

Influences on Willis

As well as consulting the publications of pioneering Egyptologists, Willis may well have been personally acquainted with a number of them. He was a founder member of the British Archaeological Association (BAA), and was President of its Architectural Section. Also a member of the original committee for the BAA was the surgeon and antiquary Thomas Pettigrew,[12] and for some years committee meetings were held at Petttigrew's house.

Willis spoke on the architectural history of Canterbury Cathedral at the Association's first Congress in 1844, at which Pettigrew unrolled an Egyptian mummy. Although there was tension from the start between different factions in the BAA, which eventually led to a schism and the formation of the rival Archaeological Institute, Willis and Pettigrew may have remained in contact, if only through mutual acquaintances. Wilkinson was a subscriber to Pettigrew's book on Egyptian mummies (Pettigrew 1834), and in Pettigrew's correspondence is a letter from Willis to Wilkinson asking to subscribe to his book on the architecture of Egypt (YUL OSB MSS 113: 13,591; Wilkinson 1850). They shared an involvement in a number of learned societies, such as the Royal Institution, where Willis lectured on architecture in 1831, Pettigrew assisted at the unrolling of a mummy in 1833, and Wilkinson attended another mummy unrolling by Pettigrew in 1836 (Pettigrew 1834 XVII). As well as providing an opportunity to

Figure 2
Thomas Pettigrew[13]

meet each other, such occasions would have brought them into contact with others active in the developing field of Egyptology, who would also have known each other. For example, another letter in Pettigrew's correspondence is from David Roberts, discussing a project involving Wilkinson (YUL OSB MSS 113: 10, 458). While not all of these personal and written connections would have involved Egyptian architecture, they indicate that Willis, a man of wide-ranging interests, would have been well placed to be aware of developments in Egyptology generally, and able to discuss them with leading figures in the field in correspondence or in person.

Willis's use of his sources

Willis never visited Egypt, and the closest he would have come to actual Egyptian architecture was the obelisks, both Egyptian and Roman copies, which he would almost certainly have seen when he visited Rome on his honeymoon in

1832. He was therefore unable to apply the same technique of forensic examination and analysis that he was to use so successfully with medieval architecture, but he otherwise approached Ancient Egyptian architecture with the same thoroughness. Some of his material is recorded using the same system and form layout that he developed for recording information on churches (Buchanan 2013, 128–9 and footnote 66).

The main body of material on Egypt (CUL MS Add. 5032) contains a chronological list of Pharaohs, including Ptolemaic rulers, drawn from Rosellini and Wilkinson (CUL MS Add. 5032: 150–152), and a chronological list of buildings drawn from the same sources (CUL MS Add. 5032: 153–161). The latter begins with a statue and chamber of 'Amenoph I' at Karnak, meaning that it starts at the Eighteenth Dynasty, around 1500 BC.[14] Although large scale stone building in Egypt goes back to around 2680 BC, and the Step Pyramid of Djoser,[15] many temples from the Old and Middle Kingdoms (c. 2680–2190 BC and 2061–1664 BC, Verner 2009, Appendix 3) were quarried for stone, or their constituent parts such as columns re-used, by later dynasties. Even where this did not happen, the original structures were rebuilt or added to and enlarged, often extensively. The best preserved temples therefore date from the New Kingdom onwards (c. 1569–1081 BC), and often to Ptolemaic or Roman times. Additionally, by the nine-

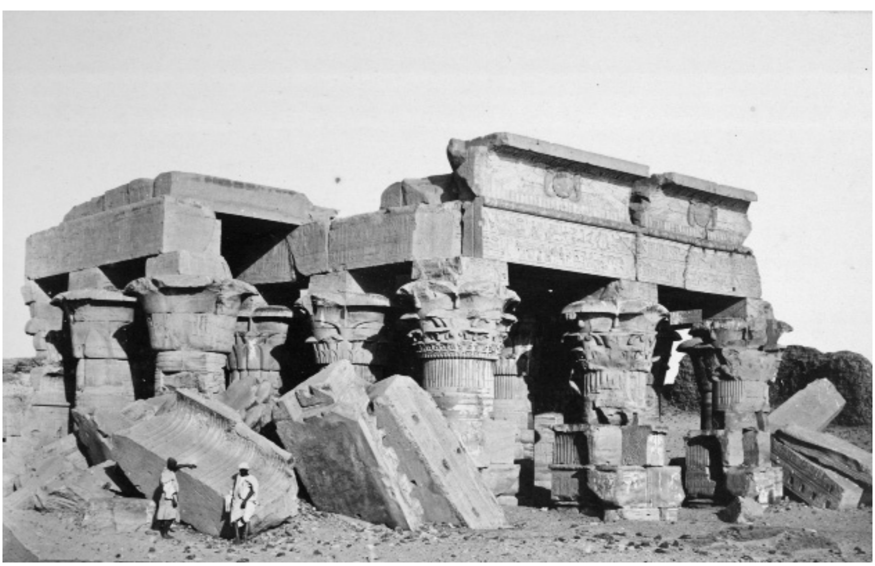


Figure 3
The temple of Kom Ombo in 1862. Photo by Francis Frith[17]

teenth century, even these were partially buried, and have undergone extensive excavation and reconstruction since Willis's time.[16]

Also in this folder is a topographical list based on Rosellini (CUL MS Add. 5032: 167–71) and notes by Willis on Egyptian columns (CUL MS Add. 5032: 181–190). Here, as well as indicating a typology of columns, he notes that Egyptian columns are unique in contracting towards the base. Elsewhere, there is a plan of tombs in the Valley of the Kings, with two columns comparing material from Wilkinson and Rosellini (CUL MS Add. 5032: 199).[18] Some idea how Willis would have dealt with his source material can be deduced from other material in the folder. There are sketches of construction elements, mainly roofs and columns (CUL MS Add. 5032: 217–232), and a chronological list of buildings with sketch plans to scale with each other, and with different functional elements distinguished by colour washes. There are also a number of sheets set out using Willis's six column layout with headings for places, buildings, parts of buildings, remarks, dates, architects and founders, and authorities, which he also used for medieval buildings (CUL MS Add. 5032: 200–207).

Another folder (CUL MS Add. 5031) headed 'Ancient Monuments' mostly consists of material on tombs, and although mentions of Egyptian architecture are scarce, they are interesting in that they show Willis comparing them with other styles. For example, on tombs in the necropolis of Petra he notes that they are: "…flat roofed & in this (?) being rightly included in the Egyptian style" (CUL MS Add. 5031: 1).[19] In other notes he compares recesses in tombs at Beni Hasan[20] and Petra (CUL MS Add. 5031: 7). A list of locations and examples of tombs starts with: "Egyptian Hypogei Beny Hassan & Biban el Moluk",[21] and goes on to include others at Petra, Greek tombs in Asia Minor and catacombs at Alexandria in Egypt, and Roman, Etruscan, Persian, Mahometan [sic] and Indian tombs (CUL MS Add. 5031: 4). In another document on "The Cruciform Chamber" in tombs, he notes that: "it does <u>not occur</u> at or in Beni Hassan or Thebes". There is material on Egyptian tombs copied from Wilkinson[22] covering shaft tombs with upper chapels "cave tombs" and burial of the poorer members of Ancient Egyptian society (CUL MS Add. 5031: 8).

Two other folders, which will be discussed below, have significant material on Ancient Egyptian architecture. One (CUL MS Add. 5130), mainly consists of notes by Willis on the development of the arch, the other (CUL MS Add. 5135), of lecture notes related to his Royal Institution lectures. (See above.)

Ancient Egypt's place in architectural history

Before considering what these papers suggest about Willis's views on Ancient Egyptian architecture, and what he might have said in his projected history of ar-

chitecture, it is helpful to put them in context by briefly examining three other views on the nature and influence of Pharaonic architecture.

Sir John Soane

As a leading neo-Classical architect, and Professor of Architecture at the Royal Academy, Sir John Soane used his lectures there from 1809 to trace the origins and development of his profession. He spoke of how

> Egypt abounds with natural excavations from which the Egyptians seem to have taken their taste as well as the first ideas of their building; and we may also observe that even in their subsequent and most splendid works they never lost sight of their primi-

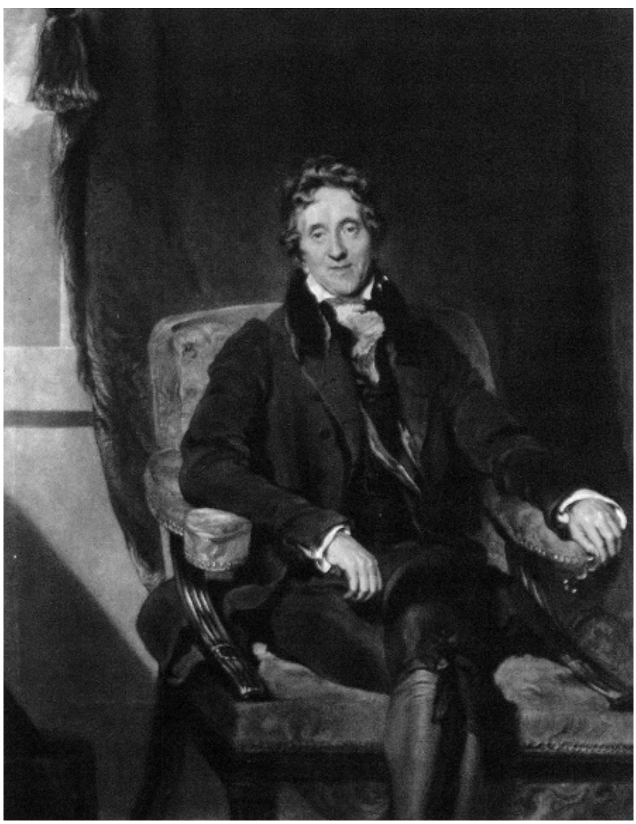


Figure 4
Sir John Soane. Watercolour by T. A. Nicholson, 1840, after Sir T. Lawrence[23]

> tive model. The cavern is perpetually the type of their architecture, and… its progress may be traced from the most simple constructions to the highest degree of excellence that the Egyptians ever attained. (Watkin 2000, 34)

While he admitted that "It is impossible not to be impressed with the grandeur and magnitude so peculiar in the works of the Egyptians in general, but particularly in their sacred buildings" (Watkin 2000, 36), he went on to observe

> But although we may be dazzled and surprised by the magnitude and solidity of these works, yet we are by no means satisfied; for, instead of… that beauty and variety which grow out of the correctness of design, instead of the graceful and harmonious disposition of parts so visible in Grecian works, we have in these only uniformity and tiresome monotony in the general forms as well as the details. Nor can we be surprised at this when we recollect that the principal features of the Egyptian architecture were taken from caverns formed in the rocks, to which they adhered so rigidly that even when round pillars were used internally, as they sometimes were decoratively (not constructively) they were rounded for use, and not for beauty." (Watkin 2000, 36)

In contrast, he saw the origins of Greek architecture in the ready availability of timber for building, and followed the Abbé Marc-Antoine Laugier in his *Essai sur l'Architecture* in seeing the primitive hut as the origin of the trabeated system of Classical architecture (Watkin 2000 p. 37, Buchanan 2013 p. 81). For Soane, it was not just a question of the historical origin of construction techniques, but of aesthetic and even philosophical superiority

> The principles of their architecture must be sought for in other prototypes than in those which gave birth to the great works of Egypt, India and Persia. Heaviness and monotony must now give place to elegant conceptions and correct conclusions drawn from philosophical reasonings. The Greeks, it must be admitted, cultivated architecture so successfully that they left to succeeding ages only the humble task of imitating their works, works which will be ever admired but perhaps never equalled. (Watkin 2000, 37)

At the time that Soane was delivering these lectures, the principles of hieroglyphic and hieratic script[24] had not yet been established, and so the writings of Classical authors remained the primary source of information on Egyptian history. The lack of a reliable chronology for Egyptian history made possible the belief that temples such as that at Edfu, actually from the Ptolemaic era, (Wilkinson 2000, 204–7) were among the oldest Egyptian architecture (Watkin 2000, 35 and footnote 36). Soane could admit that Egyptian statue pillars in the form of the

Pharaoh as Osiris (Arnold 2003, 228) might have been an influence on Greek caryatids, and that Greek mythology had borrowed from Egyptian religion (Watkin 2000, 68 and footnote g.), but still needed to assert the superiority of Greek architecture on cultural and aesthetic grounds.

Edward Augustus Freeman

Despite frankly admitting his ignorance of "Hindoo, Egyptian or Saracenic architecture" (Freeman 1849, vii, viii) before he wrote it, the first of many published works by Freeman, in 1849, was his *A History of Architecture*. His named sources for this were; Wilkinson, either the 1837 or 1847 editions of his *Manners and Customs of the ancient Egyptians*, Vivant Denon (1807),[25] Daniel Ramée[26] (1843), Arnold Heeren[27] (1833) and James Ferguson[28] (1847–8). Much of his discussion of Ancient Egyptian architecture is general, but sites he specifically mentions are Dendera, Thebes [Karnak and Luxor], Edfu, Philae, Esna, Asiut, and Abu Simbel.

Although the Willis papers do not seem to mention Freeman as a source, like Willis Freeman noted that most Egyptian column types narrowed towards their base, and he attempted a typology of columns (Freeman 1849, 70, 72). He devoted the entire second book of his *History* to the history of the arch, and in the section on Egypt cited the same engraving of the corbelled stone arch at Saqqara from c. 600 BC used by Wilkinson in his works (Wilkinson 1837, 1847) and commented on by Willis. (CUL MS Add. 5130: 42) Freeman also noted, as did Willis, the possible influence of Egyptian architecture on Christian religious buildings, seeing the large open court in front of temples, with its surrounding columns, as "calling to mind the western cloisters of the early basilicas, to which it is exactly analogous". (Freeman 1849, 72.)

Freeman showed some awareness of the chronology of Pharaonic Egypt, contrasting Thebes (in Egypt) with the "comparatively modern… Denderah and Edfou… Philae, Esneh, Syout, Elephantine", all mentioned in the *Description de l'Égypt* (Freeman 1849, 73). He noted that the name of Rameses appeared on some Nubian monuments, and that Egypt had at one period had Nubian rulers, and cited Belzoni (1820) on the temple of Dendera as "erected under one of the Ptolemies, and repaired under Tiberias Caesar". (Freeman 1849, 81, 84). Generally, however, his chronology is confused and even contradictory, seeming at one point to suggest that the temple of Abu Simbel, built by the 19th Dynasty Ramesses II could have inspired not only the largely 18th Dynasty Luxor temple, but even "the pyramids themselves", essentially 4th to 6th Dynasty, and referring to a date of 1740 BC in Wilkinson as "six hundred years after the flood". (Freeman 1849, 77, 82)

His view of Egyptian architecture, which he saw, like Soane, as originating in caves or spaces excavated in the rock (Freeman 1849, 74) can be judged by his description of it as “barbarous and uncouth… beside the meridian splendours of Athens, and disfigured by sculptures hardly less monstrous than those of the Hindoos themselves, [though] manifestly the work of no despicable intellect…Egyptian is as truly a style as a Grecian, though one of infinitely inferior merit.”

Sir J G Wilkinson

In Wilkinson’s *The Architecture of Ancient Egypt* (1850) he set out what he considered to be its six principal characteristics; battering, pylons, flat roofed temples, hieroglyphic inscriptions, winged solar disks over doorways, and pyramids, obelisks, and sphinxes (Wilkinson 1850, 31–2), and also commented on what he believed to be the origins of the system of architecture behind them. In his Preface, he attempted to arrange the rich variety of Egyptian column forms into orders, and to classify its temples “under several heads” (Wilkinson 1850, IV). Plant form columns, including various forms of papyrus, palm, and lotus, are typical of Ancient Egyptian architecture, but Wilkinson adopted a similar view to Soane and Freeman by stating that “…it may be doubted, if Egyptian columns were borrowed from the wooden supports of the earliest buildings… it is only in countries, where timber is extensively used, that architecture derives its members from wooden framework”. (Wilkinson 1850, 4) He saw the square pillar as the origin of Egyptian columns, derived from the supports left in quarries using the pillar and stall system.[29] These square pillars he believed to have been decorated with painted plants, and plant form columns as developing when square pillars began to be worked into polygonal forms, and could no longer be decorated in this way

> For the palm-tree, and water-plant, columns were not, as often supposed, in imitation of the wooden support of the early roof, but owed their origin to the devices painted, or sculptured, on the *face* of the *square pillar*, having been formed into a *capital* and *round shaft*; and the binding together of a number of water plants, to form a column, was evidently not taken from a similar frail support, but was a fanciful caprice, *borrowed* from the *relievo ornaments* of the old *pillar*. (Wilkinson 1850, 8)

Because of his extensive personal knowledge of surviving Ancient Egyptian architecture, Wilkinson, unlike Soane, recognised, mainly from tomb paintings, that domestic buildings had been of mud brick and sometimes multi-storied. He had also encountered stone roofs carved to resemble split palm trunks, but rejected the idea that these showed the development of stone built architecture from earlier plant, wood, and mud brick forms.

> …the ceiling of one of the rock tombs, near the Great Pyramid, cut to represent the palm beams of a house is another proof that the two borrowed from each other. In these, the rock monuments imitated timber roofs, but this was long after columns, and architraves, had been used in temples; and architecture was then only dependent for new features, on caprice, or taste. (Wilkinson 1850, 6)

Nowadays, the consensus is that stone built Egyptian architecture developed from pre-dynastic structures of mud brick and palm logs, or matting supported with bundled reeds, which were reproduced in the first stone buildings, and then archaised so that they provided the basic forms of dynastic Egyptian architecture (Pemberton 1992, 10–11).[30] Wilkinson saw the Egyptians as influencing Greek architecture, both through forms like the fluted proto-Doric column, and through corbelled roofs. "These two methods [of roof construction], used contemporaneously in Egypt, were both employed by the early Greeks; and they may be considered as the first steps toward the want, and the invention, of the arch". (Wilkinson 1850, 6) Unlike Soane, however, he saw no need to assert the superiority of Greek architecture.

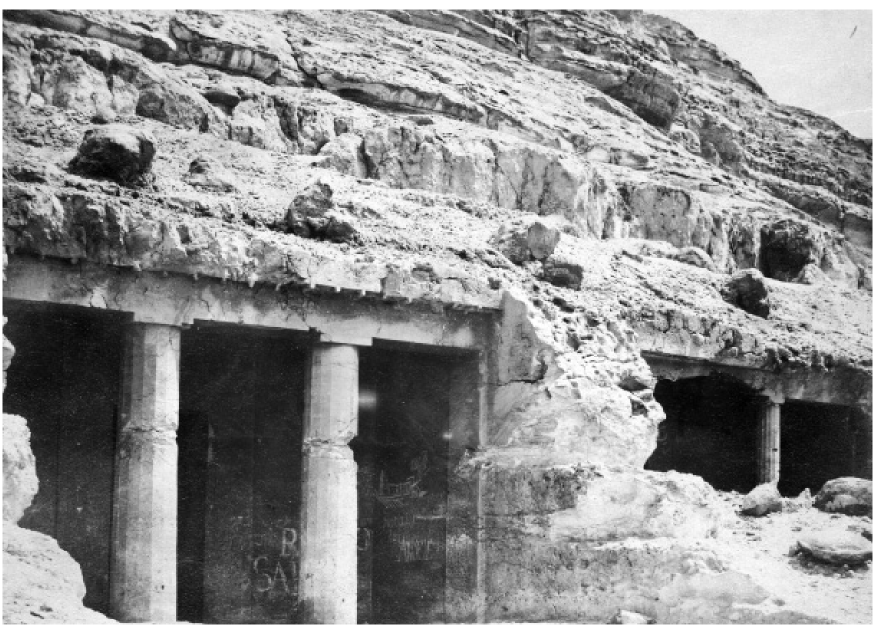


Figure 5
Tomb portico at Beni Hasan with proto-Doric columns. Photo by Antonio Beato[31]

Willis and Ancient Egyptian architecture

While the material that Willis accumulated on Ancient Egyptian architecture shows him approaching it systematically and with his characteristic thoroughness, it is, apart from a few notes, not analysed or discussed, and it is elsewhere in the papers that we can perhaps find some indications of the views that he was forming from his research.

It seems that Willis was never able to reach a final decision on the range and arrangement of topics in his proposed history of architecture. Some of the papers in the archive reflect a functional approach, a focus on particular building types, so that much of the material in the Ancient Monuments folder (CUL MS Add. 5031) deals with rock cut tombs in Asia Minor, while others focus on structural elements, such as Doors (Buchanan 2013, 156).

Arches

One folder (CUL MS Add. 5130) consists mainly of material on arches. For Willis, as for any historian of architecture, arches were of critical importance. Although he did not refer to trabeation or trabeated forms, he saw Classical architecture as a system where forces were perpendicular, with horizontal beams or entablatures and columns, and noted that: “from the moment that the arch began to shew its powers the construction began to divide into real and apparent” (Buchanan 2013, 87; CUL MS Add 5135 F.31). While it was clear that the Romans were responsible for introducing the widespread use of the arch in Europe, there were differing views over how far they had adopted it from earlier civilisations such as the Greeks and Etruscans, or those even further afield. In Willis’s notes he quotes from Wilkinson, who clearly wished to trace the origins of the arch back to Egypt, referring to a stone arch at Saqqara

> of the time of the second Psammmeticus[32]& consequently 600 years before our era. Nor can anyone who sees [?] the style of the construction doubt that the Egyptian had been long accustomed to the erection of stone vaults. It is highly probably that the small quantity of wood in Egypt and the consequent expense of this kind of roofing led to the invention of the arch. (CUL MS Add. 5130: 42)

However, Willis was not convinced, adding “He quotes an arch overhanging of stone (p. 321) dated c. 1500 BC. Why does the drawing at Beni Hassan prove the existence of a real arch? Also earliest other arch he quotes is Amenoph[33] 1540 BC of crude brick. The arch does not enter into the Egyptian decorative construction”. (CUL MS Add 5130: 43) Elsewhere, he quotes Wilkinson on Nubian pyra-

Figure 6
Vaulted stone roof at Saqqara, from Wilkinson 1847 *Manners and Customs*…[34]

mids at Napata and Meroë as being "of uncertain date, but there is every reason to believe these, as well as the small temples ~~in front of them~~ attached to their front of an age long anterior to the Ptolemies. Wilkinson V 3 [?] p. 318". Willis goes on to note that attached to the pyramids are "temples like porches vaulted with wagon vaults of stone", that some of these have arches that are segmented, and that one is pointed. He says that these have been "exactly figured by [the English traveller and lawyer] Hoskins",[35] and has copied them, one with the width of a doorway marked. (CUL MS Add. 5130: 46; Hoskins 1835, 73, 156.) He goes on to add that "Mr Hoskins concludes that the arch passed from Ethiopia to Egypt. But as the exact date of these Ethiopian remains is unrecorded this

conclusion must be classed among the doubtful hypotheses". (CUL MS Add. 5130: 46)

Lectures

The topic folders not only show Willis evaluating his source material, but may have represented sections in his proposed history. The other area where he developed his views was in lectures. We know that in the 1830s he lectured to the Cambridge Philosophical Society on the entablature in Egyptian and Greek architecture, and in the course of this put forward the suggestion that Christian church architecture had been influenced by the design of Egyptian temples. His argument for this was structural, rather than historical. The courts of temples, with their colonnades, suggested the cloisters of Christian monasteries and churches, the use of clerestory windows or openings was common to both, and the central sanctuary area and 'chapels' for the images of gods in Egyptian temples paralleled the choir of Christian cathedrals with their saint chapels (Buchanan 2013, 158).[36]

Willis delivered other lectures to the Royal Institution and at Cambridge between 1847 and 1849, and the folder of papers labelled 'Lecture Notes' probably relates to these. (CUL MS Add. 5135; Buchanan 2013, 157) His first lecture included a division of Egyptian architecture into 'rude Doric', 'Pharaonic' and 'Ptolemaic', but apart from reflecting the lack of knowledge at the time of Old and Middle Kingdom Egyptian architecture, particularly their temples, this covers a period of around 2,300 years, and offers only the most basic division of styles and eras. However, in his notes we can perhaps see a link between Egypt and ideas which were of key importance to Willis and his approach to architectural history. "Fundamental to Willis's approach was the belief that the styles were constructional systems, rather than simply combinations of ornamental features." (Buchanan 2013, 86) As early as 1835 in his *Remarks* he made the distinction between the real or "mechanical construction" of a building and its apparent or "decorative construction". (Willis 1835, 15) Later he was to write that "it is necessary that the distinction between the aesthetic character, the mechanical arrangements & the symbolism of a building should be very clearly understood…". (CUL MS Add. 5135:46) For him, it was not just the introduction of the arch that represented a watershed in the division between real and apparent form in architecture. In a series of notes he said that

> In the Egyptian and Grecian architecture of the best periods it is true that the walls are constructed of solid blocks of stone…& that the heart of the wall is as well and carefully constructed as the outer and inner surfaces. But Roman and after them Middle

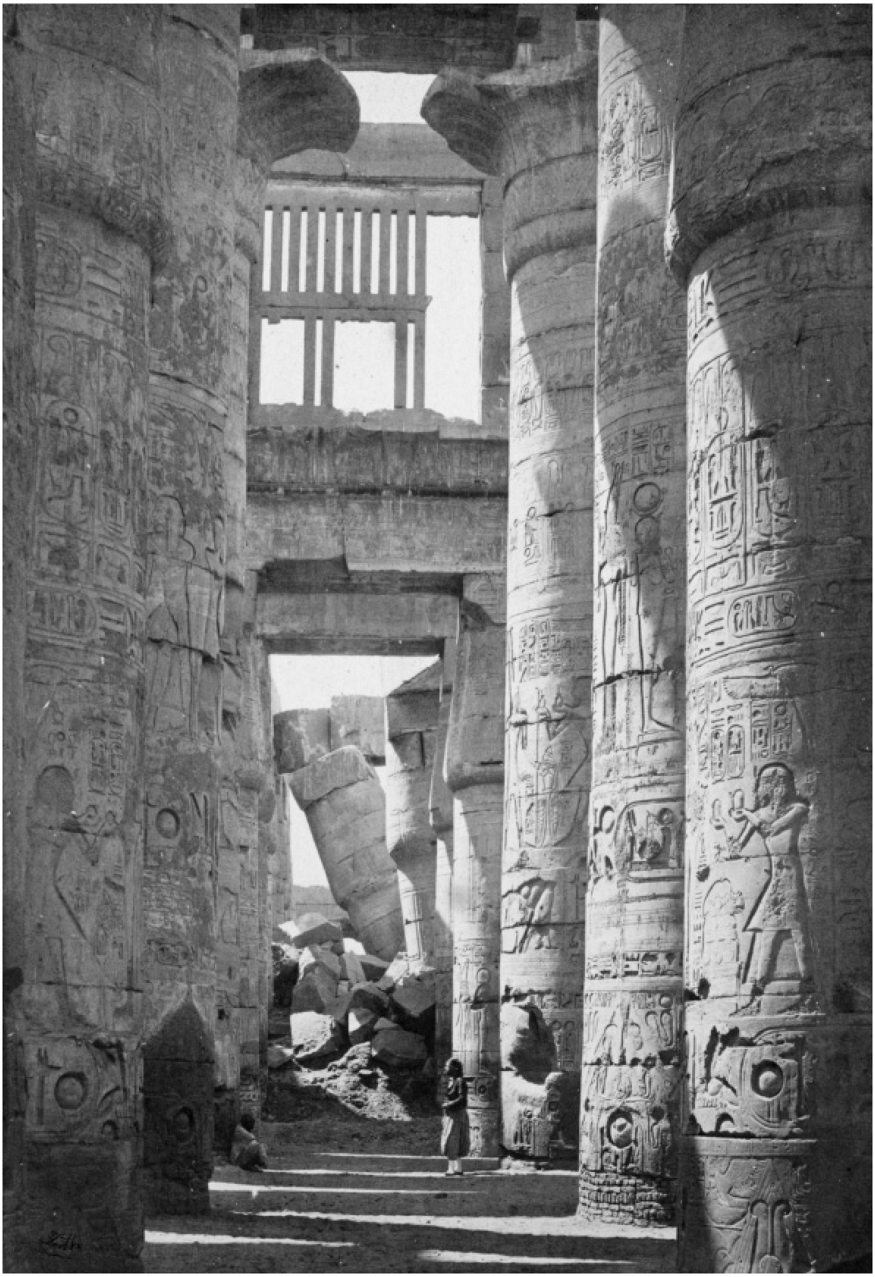


Figure 7
Hypostyle hall at Karnak showing clerestory windows. Photo by Francis Frith[37]

> Age walls are upon a totally different principle… thus the apparent stone wall is a standing deception…in truth a good honest brick wall is the only ~~one~~ wall that now answers to the principle which requires that things should be as they are what they seem. (CUL MS Add. 5135: 28)

Elsewhere he asked "For why should the labour of jointing masonry be wasted upon the inside of a wall…" but went on to observe that "nevertheless the *moral integrity* [my emphasis] of such a wall is wholly violated". (CUL MS Add. 5135: 30) Writing of Rome itself, he commented that "the same deception is practised with respect to the arches". (CUL MS Add. 5135:29) He also wrote of how such "deceptive artifices" were "practised in every style as it reaches maturity". (CUL MS Add. 5135: 31)

Despite the apparently negative tone of these comments, Willis could not conceal his fascination with the result of these artifices

> In Egyptian and Grecian architecture & in Roman before the arch enters the decoration the mechanical and decorative constructions are identical[.] The stones which rest upon the columns are merely moulded in front so as to display their form. But from the moment that the arch began to shew its powers the construction began to divide into real & apparent & when we reach the Medieval, the Pointed styles, the separation is ingeniously contrived to produce the greatest possible lightness of effect. (CUL ADD Ms 5135:31)

As an architectural historian, Willis was distinguished by his emphasis on the practical, and on constructional systems as the basis of styles, underpinned by the thoroughness of his research, including field visits, and his forensic analysis of his material. In purely practical terms, it would probably have been impossible for him to apply this level of attention and detail to the immense scope of his proposed history of architecture. Had he done more work on Ancient Egyptian architecture his approach would have fitted particularly well with the nature of its temples, which have been described as "remnants of profound religious machinery" (Wilkinson 2000, 9) where symbolic functions were achieved through a highly structured form, classically that of open courtyard, columned hypostyle hall and inner sanctuary. (Wilkinson 2000, 24–5.)

In a telling remark, he refers to "the awful grandeur of the Egyptian and Doric temples" (CUL ADD Ms 5135:44), but ultimately it was not these styles of architecture, where to use his own phrase things were what they seemed, but the 'deceptive artifices' of medieval pointed architecture which were to be the driving force behind the work for which he is now remembered.

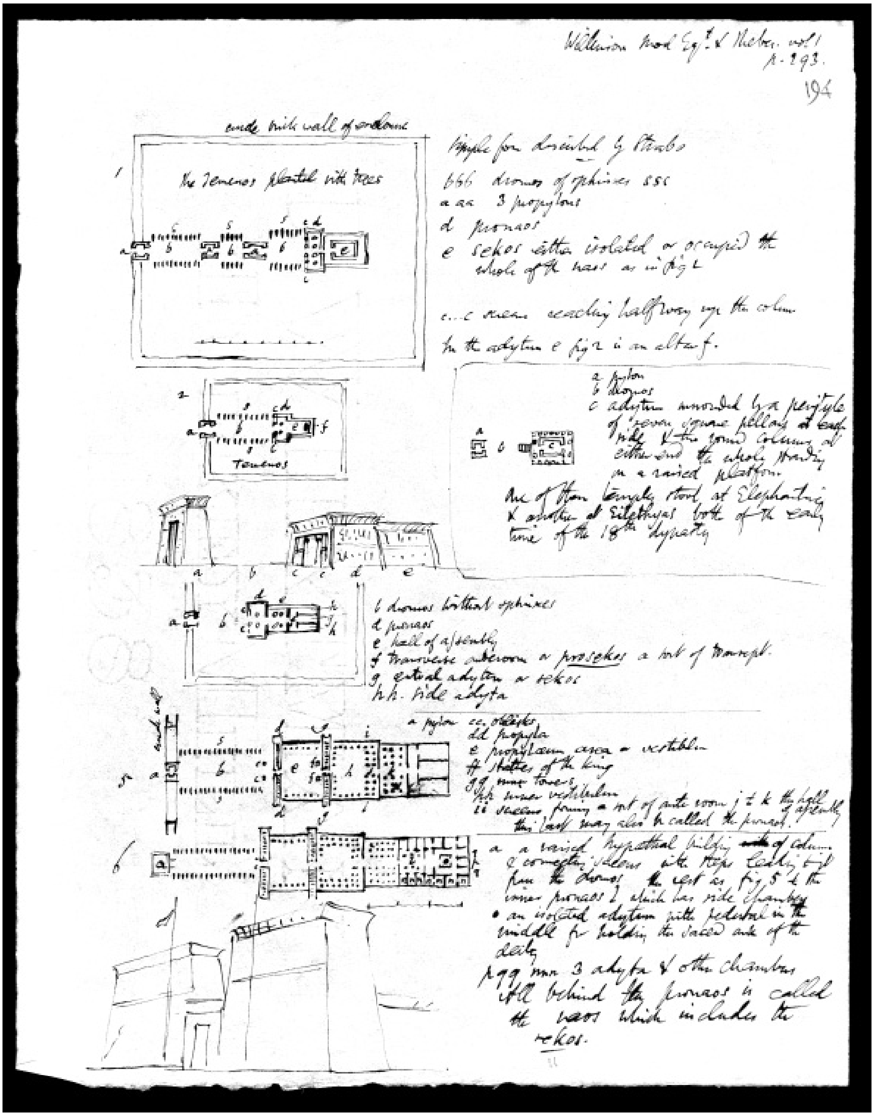


Figure 8
Sketch plans and reconstructions of Egyptian temple forms by Willis. (Cambridge University Library)[38]

Notes

I am most grateful to Dr. Alexandrina Buchanan for offering me the opportunity to examine the Willis archives, which she catalogued and prepared abstracts of, for her help with and guidance to this material, and her suggestion that I include Freeman's work. Any oversights, omissions, or misinterpretations remain, of course, my own.

1. Buchanan, personal communication by email.
2. Bierbrier (2012, 150–51).
3. General Research Division, The New York Public Library. "1. Reunion de divers fragmens d'architecture Egyptienne. 2. Plan d'un temple d'Apollinopolis." New York Public Library Digital Collections. Accessed June 26, 2016. http://digitalcollections.nypl.org/items/510d47d9-6309-a3d9-e040-e00a18064a99
4. Bierbrier (2012, 114–15).
5. Bierbrier (2012, 579–80).
6. Bierbrier (2012, 473).
7. Bierbrier (2012, 246–7).
8. Bierbrier (2012, 324–26).
9. Bierbrier (2012, 468).
10. 1815–1876. Irish surgeon, antiquary, and father of Oscar Wilde.
11. Bierbrier (2012, 52–3).
12. Bierbrier (2012, 430–31).
13. Wellcome Library, London.
14. In the nineteenth century and earlier, it was common to refer to Pharaohs by the Greek form of their names. 'Amenoph' or 'Amenophis' is now generally referred to as Amenhotep.
15. Verner (2009, 62–4).
16. A good example is the Temple of Luxor, where the Mosque of Abu Haggag, originally entered at ground level, is now perched on top of the temple, with a former entrance around six metres up a temple wall.
17. The Miriam and Ira D. Wallach Division of Art, Prints and Photographs: Photography Collection, The New York Public Library. "Koum Ombo, Upper Egypt" New York Public Library Digital Collections. Accessed June 26, 2016. http://digitalcollections.nypl.org/items/510d47d9-5c94-a3d9-e040-e00a18064a99
18. Wilkinson was responsible for the introduction of the numbering system still used for these tombs. (Reeves and Wilkinson (1996, 61).
19. Here he also cites "Roberts (with a view) Part 7" indicating that he would have been familiar with Roberts' views of Egypt, Nubia, and the Holy Land.
20. Beni Hasan (spelt Beny Hassan by Willis) in Middle Egypt is the site of a necropolis of thirty-nine rock-cut tombs of provincial leaders, in two groups, from the First Intermediate Period (c. 2190–2061 BC) and the Eleventh and Twelfth Dynasty (c. 2134–1786 BC). They are important for their wall paintings and certain architectural features, particularly an unusual fluted column style often referred to as 'proto-Doric' (Arnold 2003, 30–31).
21. Biban el Moluk is a transliteration of the Arabic name for the Valley of the Kings in Egypt, where from the reign of Tuthmosis I (c. 1504 BC) the Pharaohs of the Nineteenth and Twentieth Dynasties were buried in elaborate rock-cut tombs.

22. Probably from his *Manners and Customs*, Vol. 2 p. 397.
23. Wellcome Library, London
24. Hieroglyphs were normally reserved for monumental or religious inscriptions, and for business and administrative documents hieratic, a cursive form of the script, was employed instead. A later evolution of the script is known as Demotic (Davies 1987, 10).
25. Although Freeman (1849, 70) refers to "the little work from which we have borrowed so much", other references (1849, 73) suggest he used contributions by Denon to the *Déscription de l'Égypte* in its second, smaller format edition, known as the Panckouke edition.
26. 1806–1887. French architect responsible for a number of cathedrals.
27. 1760–1842. German historian.
28. 1809–1886. Scottish architectural historian.
29. In this system, also known as room and pillar, stone or ore is extracted horizontally, with untouched material left as pillars to support the weight of the roof thus created.
30. Pyramids evolved, via the Step Pyramid, when the construction of mud brick mastaba tombs was reproduced in stone, and then extended upwards and inwards. (Pemberton 1992, 36–41).
31. The Miriam and Ira D. Wallach Division of Art, Prints and Photographs: Photography Collection, The New York Public Library. "Beni Hassen - Nile" New York Public Library Digital Collections. Accessed June 26, 2016. http://digitalcollections.nypl.org/items/510d47d9-5fa8-a3d9-e040-e00a18064a99
32. Psammeticus, or Psamtek II was a ruler of the 26th Dynasty, c. 664–525 BC. Individual reign dates from this period, as for much of Egyptian history, are often unclear and subject to ongoing debate.
33. Amenhotep I.
34. Author's scan.
35. George Alexander Hoskins. 1802–1863. English traveller and lawyer. See http://www.griffith.ox.ac.uk/gri/4hoskins_morkot.html (Accessed 25/6/16.)
36. Interestingly, Soane also saw a possible influence on Christian architecture from Ancient Egypt. "It is not improbable that the obelisks of Egypt suggested the idea of spires…" (Watkin 2000, 141).
37. The Miriam and Ira D. Wallach Division of Art, Prints and Photographs: Photography Collection, The New York Public Library. "Interior of the Hall of Columns, Karnac" New York Public Library Digital Collections. Accessed June 26, 2016. http://digitalcollections.nypl.org/items/510d47d9-5c8d-a3d9-e040-e00a18064a99
38. MS Add. 5032: 194. Cambridge University Library.

Primary Sources

Cambridge University Library (CUL) MS Add. 5031, 5032, 5130, 5135.

Yale University Library (YUL) Pettigrew Papers. James Marshall and Marie-Louise Osborn Collection, Beinecke Rare Book and Manuscript Library, Yale University.OSB MSS 113.

Reference List

Arnold, Dieter [1994 as *Lexicon der ägyptischen Baukunst*] 2003. *The Encyclopaedia of Ancient Egyptian Architecture*. London. I B Tauris & Co. Ltd.

Bednarski, Andrew. 2005. *Holding Egypt: tracing the reception of the 'Description de l'Égypte' in nineteenth-century Great Britain*. London. Golden House.

Belzoni, Giovanni Battista. 1820. *Narrative of the Operations and Recent Discoveries within the pyramids, temples, tombs, and excavations, in Egypt and Nubia; and of a journey to the coast of the Red Sea, in search of the ancient Berenice; and another to the Oasis of Jupiter Ammon.* London. John Murray.

Bierbrier, Morris L. 2012. *Who Was Who in Egyptology*. 4th revised edition. London: Egypt Exploration Society.

Buchanan, Alexandrina. 2013. *Robert Willis (1800–1875) and the Foundation of Architectural History*. Cambridge: Boydell Press/Cambridge University Library.

Davies, W V. 1987. *Egyptian Hieroglyphs*. London. British Museum Publications.

Denon, Dominique Vivant [1802] 1807. *Voyage dans la Basse et la Haute Égypte pendant les campagnes du général Bonaparte*. London. Samuel Bagster.

Elliott, Chris. 2012. *Egypt in England*. Swindon. English Heritage.

Fergusson, James. 1847–8. *Picturesque illustrations of ancient Architecture in Hindostan*. London.

Fischer Von Erlach, Johann Bernhard. 1721. *Entwurff einer historischen Architectur, in Abbildung unterschiedener berühmten Gebäude des Alterthums und fremder Völcker, ... Alles mit ... kurtzen teutschen und französischen Beschreibungen.* Wien.

Freeman, Edward Augustus. 1849. *A History of Architecture*. London

Gillispie, Charles Coulston, and Dewachter, Michel, Eds. 1997 *Monuments of Egypt: the Napoleonic edition: the complete plates of antiquity from the Napoleonic Description de l'Egypte / edited with introduction and notes by Charles Coulston Gillispie and Michel Dewachter.* Princeton, Princeton Architectural Press.

Heeren, Arnold Hermann Ludwig. 1833. *Historical researches into the politics, intercourse, and trade of the principal nations of antiquity: Asiatic nations*. Oxford. Talboys.

Hoskins, George Alexander. 1835. *Travels in Ethiopia above the second cataract of the Nile, exhibiting the state of that country, and its ... inhabitants under the dominion of Mohammed Ali, and illustrating the antiquities, arts and ... history of the ancient kingdom of Meroe. With a map and ... illustrations, etc.* London. Longman.

Pemberton, Delia. 1992. *Architectural Guides for travellers. Ancient Egypt*. London. Chronicle Books.

Pettigrew, Thomas. 1834. *A History of Egyptian Mummies*.London.

Ramée, Daniel. 1843. *Manuel de l'histoire générale de l'architecture chez tous les peuples, et particulièrement de l'architecture en France au moyen-âge.* Paris.

Ray, John. 2007. *The Rosetta Stone and the rebirth of Ancient Egypt*. London. Profile Books.

Reeves, N and Wilkinson R H. 1996. *The Complete Valley of the Kings*. London. Thames and Hudson.

Serlio, Sebastiano. [1540] 1996. *Sebastiano Serlio on architecture / introduced, translated & edited by Vaughan Hart & Peter Hicks. Volume 1, Books I-V of "Tutte L'Opere D'Architettura et Prospetiva" / by Sebastiano Serlio*. New Haven; London: Yale University Press.

Siliotti, Alberto. 2001. *Belzoni's travels: narrative of the operations and recent discoveries in Egypt and Nubia / by Giovanni Belzoni; edited by Alberto Siliotti; [English translation by Richard Pierce]*. London. British Museum Press.

Solé, Robert, and Valbelle Dominique. [1999. *La Pierre de Rosette*. Paris. Editions du Seuil.] 2002. London. Four Walls Eight Windows.

Verner, Miroslav. [2001] 2009. *The Pyramids*. London. Atlantic Books.

Watkin, David. ed. 2000. *Sir John Soane. The Royal Academy Lectures* Cambridge. Cambridge University Press.

Wilde, Sir William Robert Wills. 1840. *Narrative of a Voyage to Madeira, Teneriffe, and along the Shores of the Mediterranean, including a visit to Algiers, Egypt, Palestine ... Cyprus, and Greece. With observations on the present state and prospects of Egypt and Palestine, and on the climate, natural history, antiquities, etc. of the countries visited.* Dublin.

Wilkinson, Sir James Gardner. 1850. *The Architecture of Ancient Egypt; ... with remarks on the early progress of architecture, etc.* London.

Wilkinson, Sir James Gardner. [1837] 1847. *Manners and Customs of the ancient Egyptians…illustrated by drawings, etc. 3 Vol. (A second series of the Manners and Customs of the Ancient Egyptians. 3 vol.)* London.

Wilkinson, Richard H. 2000. *The Complete Temples of Ancient Egypt*. London. Thames and Hudson.

Willis, Robert. 1835. *Remarks on the architecture of the Middle ages, especially of Italy*. Cambridge.

Circular stairs, polychrome stonemasonry and gormandising monks: Willis's work at Worcester

Toby Huitson

The topic of upper spaces in medieval buildings and the ways in which they functioned has been of perennial interest to architectural historians. My PhD research at the University of Kent (Huitson 2010) and now book *Stairway to Heaven: The Functions of Medieval Upper Spaces* (Huitson 2014) focuses on the evidence for the practical functions of ecclesiastical upper levels. These are defined as areas in cathedral, monastic, and parish churches and their precincts which feature permanent access to galleries, wall-passages, gatehouse chambers, upper rooms, and tower spaces. Part of my research in assembling and analysing the diverse range of original sources involved an investigation of antiquarian and historic scholarly approaches to the subject, which introduced me to the work of Robert Willis. For some sites, such as Canterbury Cathedral, his architectural histories remain seminal reading even today, nearly 150 years after his passing. This is an accolade which few, if any of his contemporaries can claim. I will return later to the question of why Willis' writing has stood the test of time so well. For the time being, it is sufficient to note that I approach the topic of Willis and his output squarely from the standpoint of a medievalist and architectural historian, and not in any means as a Victorian specialist or biographical expert.

This paper fulfils two useful purposes for the present writer. First, in my book, the historiographical discussion was necessarily condensed, and this paper provides the means to explore and amplify some aspects in more detail than was possible in the complete work. Second, it provides an opportunity to comment on research undertaken by the author since publication in 2014, including a research visit to Worcester Cathedral in July 2015 (Figure 1).[1]

Figure 1
Worcester Cathedral. Photo: Author

Worcester is a good case-study to interrogate Willis' approach to upper spaces. This was his seventh and last Cathedral architectural history, published in 1863, and one might reasonably expect it to represent a good barometer of his style refined over the previous twenty-one years.[2] I shall also draw on his work elsewhere, including references to an unpublished paper about Rochester Cathedral cited in a later nineteenth century by William St John Hope, and to his own earlier publication about Canterbury Cathedral, his first cathedral history of 1845. This article does not attempt to provide a blow-by-blow commentary on Willis' cathedral histories. Neither is it the place for a radical reassessment of upper-storey design and function at Worcester, although I shall offer some thoughts on the current state of discussions. Instead, we shall consider how Willis approached upper storey areas and what they tell us about his concept of knowledge, using some specific examples as a lens on some wider issues. To begin with, we shall first consider the broader context of upper-storey historiography from the antiquarian period to the present day.

Historiographical overview

Historical writing about the uses of ecclesiastical upper spaces has traditionally suffered from a combination of confusion, contradiction and chronic lack of reliable information. This is because after the Dissolution and Reformation the original purposes of ecclesiastical galleries and upper chambers typically fell into abeyance. By the time that early historians and antiquarians rediscovered these spaces in the eighteenth century as part of their fascination with the medieval past, their original functions had been long-forgotten, and there was little reliable evidence to indicate what they were. According to my research, writing about medieval upper spaces broadly falls into three periods or schools of thought. In the first, which ran from the mid-eighteenth to the early nineteenth century, commentators often emphasised their own ignorance alongside their fascination about the original intentions of the purposes behind the provision of medieval upper storeys. For instance, Peter Collinson wrote about Irish Round Towers in the first issue of the (then new) scholarly journal *Archaeologia* in 1770, commenting that

Various and uncertain have been the conjectures of the time of building, and use of the tall round slender Irish Towers. The application of their scanty dimensions hath puzzled our modern antiquaries... (Collinson 1770, 305–7).

This tells us three pieces of information. First, scholars were already discussing upper spaces well before 1770. Second, they were perplexed about how to interpret the evidence. Third, it was the fabric of the architecture itself which was the starting-point for discussion. This last point is crucial: there was an unques-

tioned assumption that by careful study one could ‘read’ the function from the fabric evidence alone. Despite the obvious limitations inherent in such an approach (for instance, the possibility that some spaces might have had several simultaneous functions, the possibility that uses might have changed over time, or the likelihood that some functions would have left no discernible traces in the fabric), this simplistic concept of ‘Form=Function’ would remain largely unaltered down to the present day. The Reverend Lyon summed up the approach of most early architectural investigators when visiting the ruins of St Radegund’s Abbey, Kent, in 1785, cautioning readers:

> Perhaps the inquisitive antiquary, upon a bare inspection of the several parts of the buildings now remaining, may endeavour to assign to each apartment its original use; but as this at the best will be but conjecture, I do not think it prudent to enter into such a wild field of speculation, where the wisest may err, and when the incautious must be lost. (Lyon 1787, 463–4).

Writing in the early nineteenth to the mid-twentieth century took a different approach. Scholars hastily discarded their forbears’ pretensions to Socratic ignorance, instead boldly asserting their own solutions to questions of function, even though most of these ideas were untested and many were of dubious validity. For instance, in a visit by the Archaeological Institute in 1860 to the church at Bishop’s Cleeve, Gloucestershire, a certain Mr Parker

> called especial attention to the chamber over the porch, which he said was a very peculiar specimen of the residence of a recluse. He must have been, he thought, a recluse of some importance, otherwise the expense of making a way to his chamber would not have been incurred... (Gent. Mag. 1860, 283)

This writer may well have been Willis’ near contemporary John Henry Parker (1806–1884), the renowned nineteenth-century architectural historian and writer on Gothic architecture and Roman antiquities. Typically in this period, bold assertions of scientific ‘fact’ were made by respectable gentleman-scholars based on clues in the fabric, but coloured strongly by contemporary assumptions and expectations about the medieval past. Two much-cherished opinions of the period included the hypothesis that upper spaces were frequently used as prisons or as anchorite dwellings. Prisons were especially attractive to early writers, probably because they represented the rule of law and order as opposed to the chaos of much of the seventeenth century. Contemporary parallels between the anarchy of the Civil War era and countries where law and social order was breaking down, such as in France, would not have been lost on readers. Indeed, upper-storey

prison cell hypotheses persisted well into the nineteenth century, finding their last resonance in Victorian melodrama.

In the third historiographical phase, which gathered pace through the early twentieth century, and became prevalent after World War Two, modern historians chose to attack what they saw as vacuous Victorian pretensions to knowledge, claiming instead that not only that little was known about the uses of these spaces, but also that it was impossible to know —a distinctly post-modern stance, but one curiously reminiscent of the former antiquarian standpoint. The modern architectural historian Roger Stalley poses the tantalising question:

> In Normandy and England… clerestory passages are one of the most exciting features of English Romanesque… offering exhilarating vistas for those fortunate enough to experience them. What purpose was served by these semi-secret passages high in the walls of the church? (Stalley 1999, 202–3).

Stalley is right to express caution here: the uses of clerestory passages are indeed difficult to fathom. However, it is framed as a rhetorical question which is left unanswered. As we shall see, these were also questions which Robert Willis wrestled with in his work at Worcester.

Although Willis is famous for his Cathedral histories, the genre did not, of course, emerge from a vacuum. One of Willis' most famous predecessors was John Britton (1771–1857), Fellow of the Society of Antiquaries and author of *The Beauties of England and Wales* and the *Cathedral Antiquities of England*. The introduction to his *History and Antiquities of the Cathedral Church of Hereford* published in 1831 (eleven years before Willis' piece on the same topic) shows that, like Willis, Britton's approach was based on personal inspection and archival research (Britton 1831, vi). He specifically tells us that he was more interested in presenting his own ideas than adopting the existing prejudices and dogmas of other commentators, suggesting that this was a widespread practice at this time (Britton 1831, vii). However, Britton's style is very different in tone to that of Willis': it is highly verbose, and he devotes much effort towards advancing taste and value judgements which reflect the interests of his intended audience, who would probably be the purchasers of a luxury limited-edition volume for the gentry. Britton's illustrative plates were numerous and often reproduced through the nineteenth century, and it may perhaps have been partly through him that the benchmark in this respect was set.

Willis and upper spaces

It is clear without a shadow of doubt from Willis' many publications that he was interested in gaining access to the upper levels of churches and cathedrals. The en-

gravings which accompany his accounts frequently show views from inside triforia (for instance, see Willis 1845: 49). There are frequent discussions of stairs, with their locations clearly labelled and identified with a reference on plans. He also comments on the provision of wall-passages. His first, and arguably most famous architectural history, was that of Canterbury. Willis shows his eye for detail here, noting that square abaci were used throughout the Canterbury triforium, drawing a parallel with those at Sens (Willis 1845: 95). In a rare moment of speculation amidst his usual scientific rationalism, he writes (see Figure 2):

> The mechanical construction of the clerestory in William of Sens' choir is somewhat singular, and is shewn in the transverse section ... The floor of the clerestory gallery *R* is carried by the triforium arches, but the thin wall of the clerestory windows rests upon a segmental arch *S* , which springs from the buttresses, and the crown of this arch is so high, that it rises even above the pavement of the clerestory gallery, leaving a small opening by which persons in the latter gallery can see into the triforium below at *Q*, and hold communication with persons therein. (Willis 1845: 96)

Figure 2
The south triforium arcade at Canterbury Cathedral, showing the opening in the screen wall to which Willis refers. Photo: Author.

Willis' publications make it clear that he was interested in upper spaces as places of exploration, principally because they might provide useful evidence for his central objectives of ascertaining design principles, construction techniques, and historical sequencing. It is not entirely clear if his great work on vaulting (published in 1842, and republished posthumously in 1910) arose from his early forays into roof spaces, or if he first became interested in vaults as an object of mathematical investigation, and then sought ways to gain access to them. Certainly, in contrast to his Canterbury piece, this paper makes no reference to stairs or galleries, suggesting that it was the vaults themselves which were the first object of his fascination.

An interesting sidelight on Willis is provided by the man who was probably his most famous successor in the field of medieval architectural history in the later nineteenth and early twentieth centuries: William St John Hope (1854–1919). St John Hope was Willis' junior by fifty-four years, with his first major publication appearing in 1881. His output included numerous excavation reports, including pieces on Kirkstall Abbey, Leeds; the site at Old Sarum, Wiltshire; and publications spanning heraldry to the Roman site at Silchester. Hope's architectural history of Rochester Cathedral appeared in 1898 and provides an insight into his admiration for Willis. In some ways, Hope's report on Rochester offers a parallel for Willis' on the monastic precinct at Canterbury: both pieces appeared in the journal *Archaeologia Cantiana*, and both authors wrote separate surveys of the Cathedral church and monastic precincts. However, one major difference lies in the fact that Hope's Rochester article was, by his own admission, written to revise and correct some major lacunae in his earlier work of 1883 and 1884. Indeed, Hope's posthumous reputation seems to have suffered much more than Willis', due to his work being dogged by a frequent claims of factual inaccuracies.

An indication of the esteem (or otherwise) with which Hope regarded Willis is apparent where the writer states that 'The architectural history of this part of the church cannot be better described than in the words of the late Professor Willis' (Hope 1898, 233). He then proceeds to quote no less than ten pages verbatim from a lost paper by Willis on Rochester. This might, on first glance, appear to represent an affirmation of undying respect for the elder academic. However, all is not as it seems: the extended quotation is peppered with footnotes, errata, and miscellaneous corrections. For instance, Willis' description of alternating bands of ashlar masonry and rubble in the clerestory at Rochester is bluntly footnoted by Hope: 'This is not the case'. (Hope 1898. 237). Elsewhere, however, the quotation reveals something of Willis' working methods. A particular problem at Rochester which Willis encountered was that the clerestory passage, built as a continuous pathway around the choir and presbytery, had unfortunately been

blocked in various places by recent masonry reinforcements. Willis noted that some sections of the passage could be reached by the stairs, but that ‘the other parts of this gallery can be reached only by ladders’. (Hope 1898. 239).

Willis at Worcester

Willis’ work at Worcester shows him in his element. An instructive insight into his working methods in the triforium at Worcester is found on pp. 95–6 of his 318-page account. Here, Willis observes that Norman windows remained above the triforium doorways. Therefore, he reasoned, the west wall must be original, and if this was so, there must have been no western towers, or at least ‘there are no traces of their existence in the triforia or elsewhere’ (Willis 1842: 95–6). There is more than one way of interpreting this statement. One possibility is that he entered the galleries with the specific intention of identifying such evidence, but that he was unable to find any. Alternatively, it indicate that he did not happen to notice any specific evidence for towers while touring around the upper spaces. Of course, the evidence could have been destroyed by later Romanesque rebuilding, or simply have been inaccessible and therefore invisible. For Willis, seeing was undoubtedly believing. Anything which could not be seen was assumed to not be present. Only by peeling back the layers of history (either metaphorically or literally) could the truth be revealed. This approach is seen in its most literal guise at Worcester, where Willis writes that the internal walls of the transepts ‘were, at my request, scraped of their plaster’ (Willis 1863: 96). This revealed that the transept stair turrets in their lower courses were comprised of striped bands of coloured stone, ‘the one a white or rather cream-coloured stone, the other a green stone’ (Willis 1863: 97).[3] Similar decorative techniques were found to exist elsewhere in the building, such as the chapter house, when the covering whitewash was likewise ‘obligingly cleaned at my request’, revealing the spectacular green and white polychrome stone to maximum effect (Willis 1863: 98).

He also notes that the triforium and clerestory ‘were *not yet* scraped at my last visit, and I cannot therefore describe them’ (my italics). (Willis 1863: 98). The implications of this latter statement are clear: first, this was work in progress which he expected to be taken in hand, and second, without investigation, there could be no discovery.

This revelation about Willis’ literal action on the building is worth pausing for a moment to reflect on. It shows first of all his influence that such drastic activity could be initiated by a visitor, albeit a very well-connected one. Of course, the rather alarming possibility to modern readers that original wall-paintings or post-medieval evidence might have been destroyed in the process does not seem to

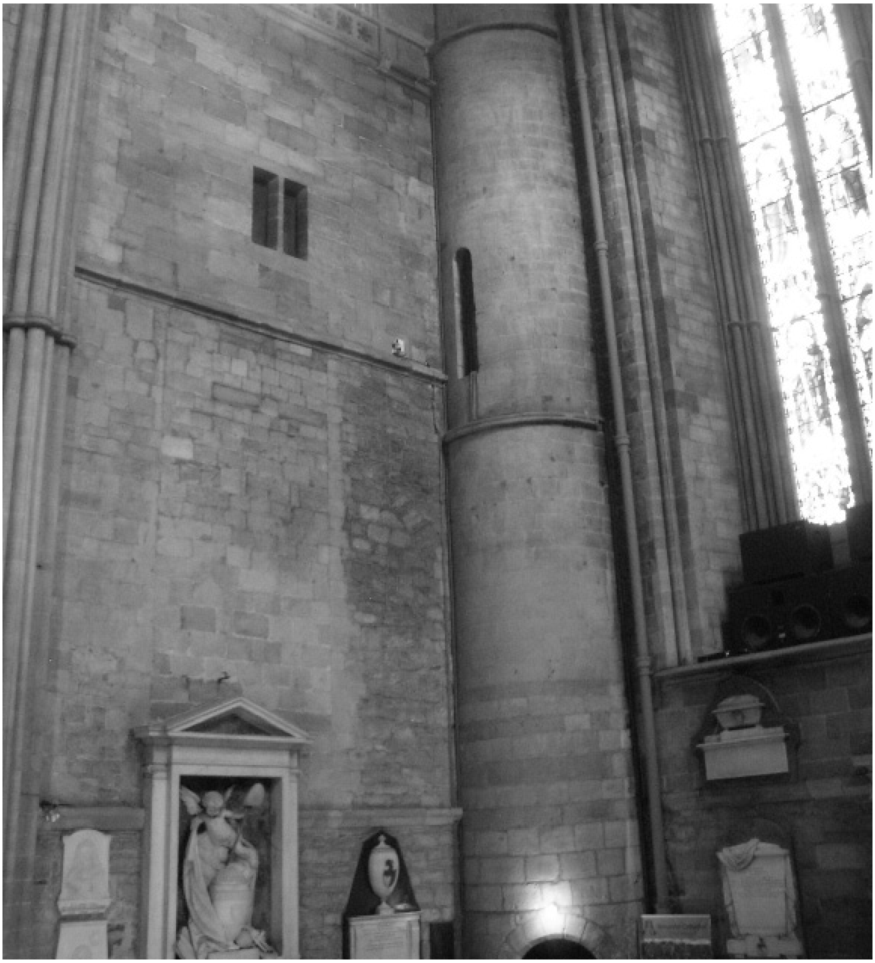


Figure 3
Stair turret in the north transept at Worcester Cathedral, with striped masonry in its lower courses. Photo: Author

have been a major preoccupation at the time. However, there is a much bigger point at stake here. The word 'scrape' is highly loaded in nineteenth-century architectural history, particularly with reference to the Society for the Protection of Ancient Buildings (SPAB), otherwise known to contemporaries as the 'anti-scrape' movement. The SPAB was founded in 1877, fourteen years after Willis' publication on Worcester. Normally directed against over-zealous restoration, it

Figure 4
Interior of the chapter house at Worcester. Photo: Author

shows us how invasive archaeological detection work could equally have been another source of contention.

Later modifications to the fabric seldom escaped Willis' notice; indeed, unravelling these seems to have been a core part of his mission. For instance, he writes that the upper part of one of the transepts at Worcester had been 'tampered with' by a Perpendicular window and vault (Willis 1842, 96–7). In using such language, Willis parallels the work of architectural historians such as John Bilson (1858–1943) for whom recovering original chronologies and designs was a primary concern, and for whom later modifications were regarded as something of an inconvenient distraction. Willis' criticism of others is always diplomatic and fair. For instance, he offers a perceptive comment on Worcester's lost bell-tower, illustrated by Wenceslas Hollar in 1672 for Dugdale's *Monasticon*, stating that 'It appears wholly destitute of architectural ornament or beauty – probably because the decay of the stonework had reduced the surface and destroyed the angles and details of the masonry'. (Willis 1863, 260). This could be described as an enlightened approach, avoiding the obvious temptation to criticise Hollar for poor draughtsmanship or clumsy understanding of medieval architectural ornament in the seventeenth century. Another example of Willis' judicious diplomacy is where he states that he favours the retention of original fabric, but that the Perpendicular window east of the tower had been replaced in 1792, wryly remarking 'which Mr Wild says nearly resembled the one which preceded it, but which was evidently deficient in many essential particulars' (Willis 1863, 126).

Willis was also excited about another feature of the transept spiral stairs at Worcester: 'At the south corner of each transept is a circular stair-turret, which is remarkable for its unusual projection into the church'. (Willis 1863, 97) (see Figure 2, above). Despite his expressions of surprise, other parallels are easy to cite, such as that inside the chancel at Hythe parish church, Kent, or that at Christchurch Priory, Dorset, articulated and embellished on the outside of the building. Likewise, Willis draws attention to the presence of low-level wall-passages at the cathedral 'in the manner very common in clerestories, but unusual for windows near the ground' (Willis 1863, 104), Figure 5.

The reasons why such a low-level passage was built (similar to that found occasionally elsewhere, such as in the presbytery at Tynemouth Priory, Northumberland) are not explored further, but it tells us much about what attracted his attention. Willis also described the different height of the triforium and clerestory in the Norman and Gothic schemes at Worcester at some length, but again without reaching a firm conclusion about why this might have been so,[4] Figure 6. We could interpret these cases as good examples of scholarly circumspection and restraint as much as avenues which remain tantalisingly unexplored.

Figure 5
The low-level wall-passage in the south transept at Worcester Cathedral, visible immediately above the ground-floor arcade. Photo: Author

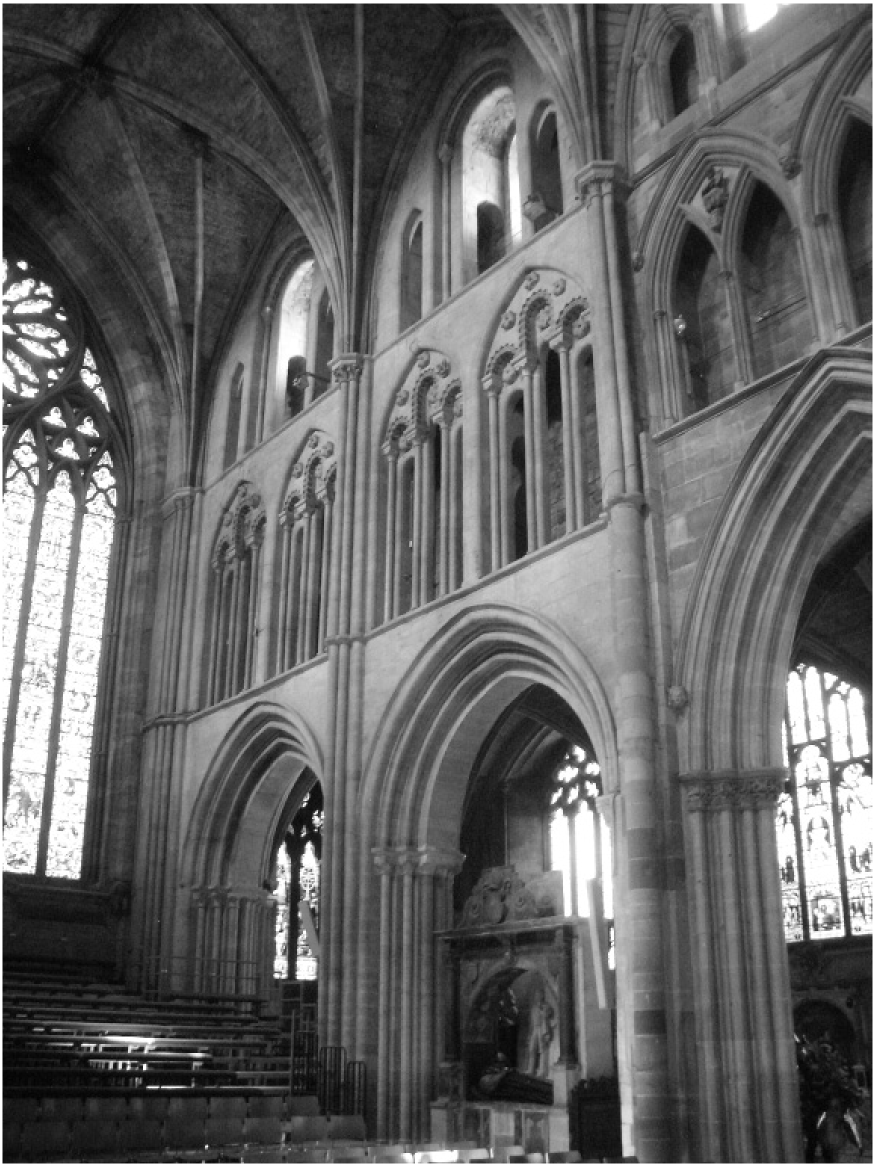


Figure 6
South side of the nave at Worcester Cathedral, showing the join between the late Romanesque and Gothic elevations. Photo: Author

One of the most interesting (and amusing) sections of Willis' Worcester account is his discussion of the treasury chambers above the slype, adjoining the chapter house.[5] This is unusually complex, with several different chambers, doors, and a stone-vaulted mezzanine gallery (Figures 7 and 8).

Figure 7
Interior of the main vaulted chamber in the Treasury at Worcester. Photo: Author

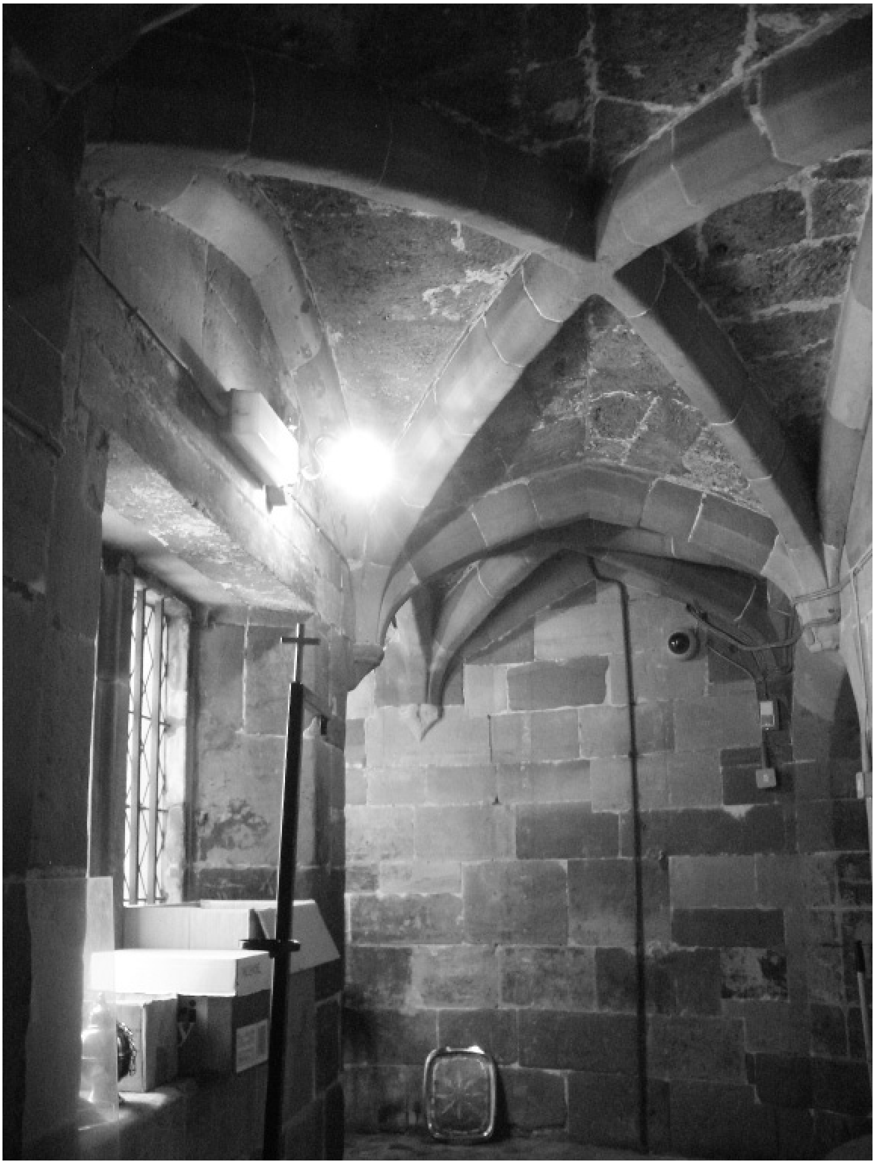


Figure 8
Interior of the vaulted mezzanine upper chamber in the Treasury. Photo: Author

It came towards the end of what can only be described as a frenzy of building activity at Worcester over the ten years spanning 1368–78, including major vaulting work, a new dorter, library, gatehouse, choir stalls, west window, internal paving, and the construction of various screens. Worcester was certainly not averse to finding unusual solutions for its functional requirements: its library housed in the nave triforium, for instance, has no other direct parallels. Willis was well aware that he was by no means the first commentator to discuss the Worcester treasury. He mentions the thoughts of one earlier scholar in detail (see Figure 9):

> The treasury is described by King in his *Munimenta Antiqua*... he calls it *the Monk's Prison* and explains the arrangements on that hypothesis... He does not appear to have found his way into the west chambers of the treasury. In the north wall of the great room, on the left side of the narrow staircase door, is a square recess... Of the narrow doorway near it he absurdly remarks, that 'It would be allowing an idea much too ridiculous to apprehend that this doorway was designed as a *gauge* for any fat, gormandizing, gluttonous monk, who might be confined here till he should be able to pass through it'. (Willis 1865, 266)

Figure 9
Detail of the narrow doorway and recess in the treasury wall. Photo: Author

Willis references and quotes here from the eighteenth-century barrister and writer Edward King and his four-part volume of 1799 (King 1799, IV: 157). Like many antiquarians, who were convinced that upper chambers in churches often functioned as prison cells, King believed that this was the case at Worcester, citing other supposed ecclesiastical prison cells including the so-called 'Old Bakery' chamber over St Anselm's chapel at Canterbury Cathedral. This function of this upper chamber, which was probably built as a Romanesque upper chapel and later converted around 1390 for use by the Canterbury Shrine Wardens, had been the subject of protracted antiquarian discussion and correspondence in the 1770s. (Huitson 2013). Although it is difficult to be sure, at Worcester it may have been the palpable sense in which King embellishes and relishes in the myth (…for any fat, gormandizing, gluttonous monk) which Willis particularly objected to. The re-telling of the fable complete with imaginative reconstructions could have been regarded not only as unscientific, but a hindrance in moving the state of knowledge forward. This sentiment finds a ready parallel in Gostling's writing about the Old Bakery chamber at Canterbury in 1774 where he writes dismissively about a popular myth that the King of France was once confined in the room as 'too ridiculous for confutation'. (Gostling 1774, 151–2). As here, the hypothesis is cited in order to debunk it, although in the process draws attention to the idea, ironically giving it a measure of objective validity and increasing its circulation. However, in this instance, Willis was not yet willing to let the subject of monastic obesity lie in peace. After having criticised King's dubious stories of dieting monks as 'absurd', four pages later, Willis mentions the north wall of the dormitory with its 2ft 3inch wide spiral stair, adding in tongue-in-cheek fashion '...and therefore just sufficient for a single person to ascend, unless he had attained to the diameter popularly supposed to characterise a monk'! (Willis 1863, 270). This shows that he had a good sense of humour.

Conclusions

In this article we have considered Robert Willis and his place in historical writing about medieval upper spaces. We have seen something of his methods and enquiring mind, the sense which he made of the evidence before him, and the efforts he went to in order to reveal or gain access to it. The act of scraping walls, including those of stairs and gallery-spaces, shows his approach to knowledge as something which had to be purposefully investigated and revealed, rather than something acquired on a casual or superficial basis. Such techniques of the large-scale removal of plaster, although frowned on by later generations who saw them as destructive and aesthetically displeasing, nevertheless revealed striking long-lost decorative schemes, influencing the appearance of buildings as we still expe-

rience them today. Evidence could equally be a source of confusion and disagreement, especially in the case of treasury chambers. The narrow doorways, additional doors, draw-bars and grilles which were often provided in treasuries are best understood as security features which could be applicable both to treasuries as well as prisons. Such features however seem to have been a source of confusion for early writers, who assumed they were looking at evidence for one or the other, and marshalled their evidence accordingly to suit. Unlike many of his contemporaries, Willis sometimes chose to leave questions of function unanswered if he felt there was insufficient evidence to make a conclusive statement.

Why, then, is Willis still a touchstone of reference to architectural historians in the twenty-first century? I suggest there are several reasons. He avoids empty speculation (unlike St John Hope) and had great self-belief (unlike many self-deprecating eighteenth-century commentators), using both written and archaeological evidence to build up a rounded or interdisciplinary picture. His writing is detailed and scientific, yet remains readable, and he addresses an educated popular audience rather than a narrow aristocratic readership. An expert with popular appeal, and a professor who conversed with ordinary workmen during his visits, Willis was confident enough to propose his own interpretations without over-reaching his limits. He avoided harsh judgements about the aesthetic sensibilities of previous architects' restoration work and treated others with tact and diplomacy. Willis was also witty, poking fun at ideas which only a few pages previously he had firmly admonished. Finally, he was a polymath combining a set of proficiencies which it is difficult to match even today: a translator who was simultaneously a geologist, and a liturgist who was equally at home being a mathematician and historian. It was indeed no exaggeration when the late professor and medievalist Christopher Brooke (Brooke [1993] 2004, 476) summed up his eminent Cambridge predecessor as 'the grand master of architectural history.'

Notes

1. I am grateful to Chris Guy, Cathedral Archaeologist, for kindly showing me around the upper spaces at Worcester, and to Tim Tatton-Brown for suggesting the visit.
2. For instance, Willis draws parallels with Gloucester and Durham, which he presumably knew very well , even though neither was the subject of one of his seven cathedral monographs (Willis 1869, 262).
3. Willis cites the black and white striped marble at the Italian cathedrals of Pisa and Siena as parallels for the polychromy at Worcester. He may have been unaware of other examples of polychrome masonry closer to home, such as that in the thirteenth-century nave at Deerhurst, Gloucestershire, or in the presbytery at Castle Acre with a cream and rust-brown combination (the latter perhaps an ironstone conglomerate). A three-way combination in a high-level context may be seen in the thirteenth-century first-floor refectory 'high table' end wall at Canterbury, with a mixture of cream Caen

stone, dark grey Purbeck 'marble', and light green ragstone, which parallels the treatment of the contemporary ground-floor north cloister arcade.

4. One could say that the triforium was gradually losing its importance as a structural unit due to the emergence of other upper-level performance spaces such as the *pulpitum*.
5. Willis refers to his description of the building with detailed plans in the Transactions of the Institute of British Architects, due to be published concurrently at the time of writing.

Reference

Britton, J. 1831. *History and Antiquities of the Cathedral Church of Hereford.* London.

Brooke, C. N. L. 1993. *A History of the University of Cambridge: IV*. Cambridge . Revised edition. 2004.

Collinson, P. 1770. An extract relating to the Round Tower at Ardmore, in Ireland. *Archaeologia* I, 305–7.

Gostling, W. 1774. *A Walk In and About the City of Canterbury, With many Observations not to be found in any Description hitherto published.* Canterbury.

Hope, W. H. St John. 1898. The Architectural History of the Cathedral Church and Monastery of St Andrew at Rochester. *Archaeologia Cantiana* 23. 194–328.

Huitson, T. 2010. Hidden Spaces, Obscure Purposes: The Medieval Ecclesiastical Staircase, Gallery and Upper Chamber in East Kent. Unpublished PhD thesis, University of Kent.

Huitson, T. 2013. The Mystery of the so-called 'Old Bakery' chamber over St Anselm's chapel, Canterbury Cathedral. *British Archaeological Association Conference Transactions* 37. 204–216.

Huitson, T. 2014. *Stairway to Heaven: The Functions of Medieval Upper Spaces*. Oxford: Oxbow.

Lyon, J. 1787. *Bibliographica Topographica Britannica* Vol. XLII. London.

King, E. 1799. *Munimenta Antiqua* in 4 vols. London

Stalley, R. 1999. *Early Medieval Architecture.* Oxford.

The Gentleman's Magazine 1860. Vol. 209. London.

Willis, R. 1845. *The Architectural History of Canterbury Cathedral*. London.

Willis, R. 1863. The Architectural History of the Cathedral and Monastery at Worcester. *Archaeological Journal* 20.1–318.

Building on Robert Willis at Chichester Cathedral

Tim Tatton-Brown

I first "discovered" Robert Willis forty years ago, just after I had gone to Canterbury to be the first director of the Canterbury Archaeological Trust. At that time, I was largely a digging Roman archaeologist, though I had a particular interest in upstanding Roman buildings and Roman building materials. In 1976, I was invited to be the honorary consultant archaeologist to Canterbury Cathedral, and we were soon doing excavations, for the King's School, in the Precincts, and at the Dean and Chapter's private conduit house (Tatton-Brown 1983). Reading Willis's two great works on Canterbury (Willis 1845 and 1868) was the perfect background to this archaeological work, and I soon realised that we could build on Willis's brilliant pioneering work, both on the Cathedral itself and among the remarkable surviving remains of the largest Benedictine monastery in Britain. Willis's volume on the Cathedral, and particularly his remarkable detailed analysis of Gervase's account of its rebuilding after the fire of 1174, is now well-known (Willis 1845). Less studied, however, is Willis's extraordinary analysis (Willis 1868, 174–181) of the two unique "Waterworks plans" of the mid-12th century, that are bound into the Eadwine Psalter, in in Trinity College, Cambridge (Gibson, Heslop and Pfaff 1992). Starting with the main "Waterworks plan" Robert Willis was able to investigate Prior Wibert's new piped water system, and then move on to study most of the monastic buildings in the Precincts, and to transcribe many of the key documents relating to them. This included the "Distribution Document" of 1546, which showed how many of the monastic buildings were carved up for reuse by the Dean and Chapter after the dissolution (Willis 1868, 192–6). Willis's architectural history of Canterbury Cathedral Pri-

ory and all its buildings was then unsurpassed until the early 1980s, when new surveys of the buildings were undertaken by Margaret Sparks (Sparks 2007), John Bowen (now Jill Atherton) and myself in preparation for the new official history of Canterbury Cathedral (Collinson, Ramsay and Sparks 1995, plans 1 and 2. See also Tatton-Brown 1984). By this time, a small number of other people, like Warwick Rodwell (at Wells and Lichfield) and John Crook (at Winchester) were also building on Willis's work at other cathedrals, and a new era of cathedral archaeology had started (Tatton-Brown and Munby 1996). One should add that a few scholars had continued Willis's own "cathedral archaeology", after his death in 1875; the most notable being Sir William St. John Hope, who brilliantly completed and enlarged on Willis's work at Rochester Cathedral and Priory (St JohnHope 1900). He sadly died in 1919. After the First World War, when a new age of "digging archaeology" began, led by Sir Mortimer wheeler, Willis's work on "buildings archaeology" largely sank into oblivion, and even today very few archaeologists are aware of his work (Tatton-Brown 1989, 211–18). Ironically, it was the great art-historian, Sir Nikolaus Pevsner, who championed his work in the later 20th century (Pevsner 1970) and used Willis's analyses of many English cathedrals as the basis of his descriptions in the "Buildings of England" volumes (see Pevsner and Metcalf 1985). In my brief history of cathedral archaeology, written nearly thirty years ago, I called Robert Willis "the father of British cathedral archaeology" and said that his work "deserves to be better known (Tatton-Brown 1989). Sadly, among most archaeologists, this is still not the case, even though, under the Care of Cathedrals Measure 1990, every English cathedral is required to have a "consultant archaeologist."

Chichester Cathedral

I was lucky to be appointed "consultant archaeologist" to Chichester Cathedral, by the Dean and Chapter, in 1987, and this quickly led on to a very fruitful five years of recording and studying the fabric of that cathedral during a period of major stone restoration. Detailed measured drawing work, starting in 1988, was initiated by Fred Aldsworth and then carried on by John Atherton Bowen (now Jill Atherton). We soon realised that, at Chichester, different building stones and masonry types were used for almost every stage of the building work between *c.* 1076 and *c.* 1530, which allowed each phase to be easily identified. Willis had also known this. Also, all the periods of rebuilding and restoration in the 19th and 20th centuries could be discovered by the use of more "modern" building stones like Portland and Bath stone. Behind all our work, however, was Robert Willis's remarkable analysis of the whole building for the Archaeological Institute's summer meeting in Chichester in July 1853. Unfortunately, though Willis prepared

his work for publication immediately, it was not published by the Institute, due to the “tardiness” of other contributors to the meeting. Nearly seven years later, Willis returned to Chichester early in 1860 to advise on the removal of the Arundel screen from the western crossing. Work got underway on this later in the year, and on the refurbishing of the choir. This was overtaken by a catastrophic event, the fall of the tower and spire on February 21st 1861. Willis then immediately returned to Chichester and carefully studied the ruins like a forensic scientist. He quickly lectured on his findings and published his 1853 work with an “introductory essay on the fall of the tower and spire” (Willis 1861). This masterly “essay” starts with a survey of all previously documented collapses of medieval towers in England, as well as a discussion about successful repairs. Willis then continues with a structural survey of Chichester Cathedral before describing in detail all the events leading up to the final telescopic collapse of the tower and spire into the crossing at 1.00 pm on February 21st 1861. His dramatic narrative makes very exciting and compelling reading. Here is the climax:

> On Thursday, the 21st, before daylight, the work was resumed. Seventy men working with most commendable enthusiasm and courage, under great personal risk, made strenuous efforts to increase the number of shores, under and around the tower; for those applied only the night before were bent and the danger became more and more imminent. The workmen were only induced to quit the building by the inevitable dinner hour of noon. But, by this time the continual failing of the shores, showed, too plainly, that the fall was inevitable. Warning was given to the inhabitants near the building, on the south-west, and the workman, returning at one, were prevented from re-entering it. Anxious groups, outside the cathedral enclosure, stood gazing at the tower, and in less than half-an-hour, the spire was seen to incline slightly to the south-west, and then to descend perpendicularly into the church, as one telescope tube slides into another, the mass of the tower crumbling beneath it. The fall was an affair of a few seconds, and was complete at half-past one. (Willis 1861, xviii)

When Willis returned to Chichester a few days later, he made careful drawings of the crossing area, showing all the masonry breaks, and indicating where the earlier fissures had been. He then analysed:

> more minutely the history of the failure of the south-west pier, which was the weakest. It began slightly to bend to the south in the middle of February last: this was shown by the closing up of the old fissures, which divided it from the transept…The eastern respond of this pier, belonging to the south tower arch, began to split from top to bottom (CD, Fig. 1) and a fissure extending into the nave arch became manifest. On the Sunday preceding the fall, the bulging of the facing of the pier was observed to in-

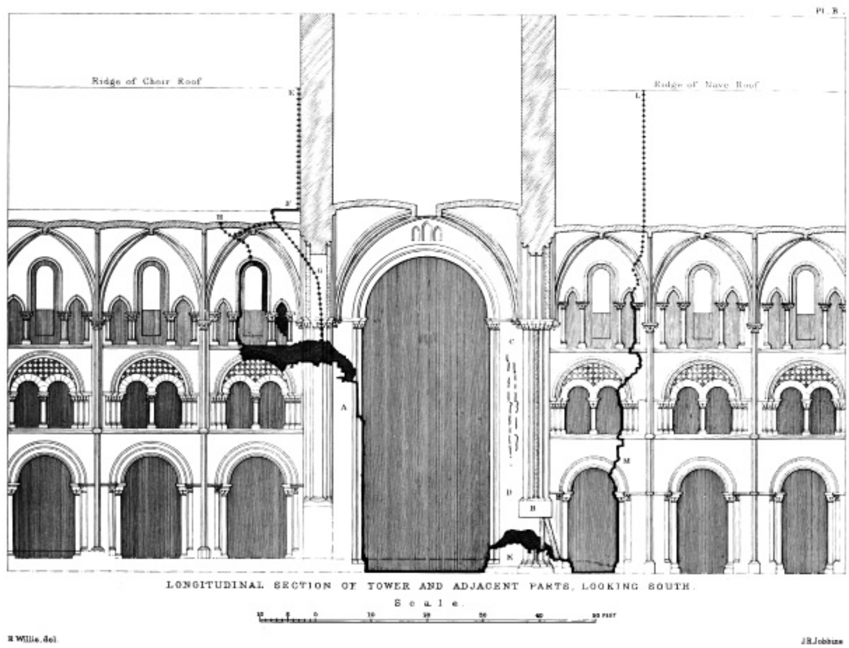


Figure 1
Longitudinal section of tower and adjacents parts looking south (Willis 1861, Plate B)

> crease so alarmingly, that men, as already stated, were set to work to apply shores, during the service in the nave. This bulging increased on the succeeding days, rapidly, and the arches of the triforium assumed gradually the peculiar elliptical form, which is produced by the unequal settlement of the piers of a semicircular arch. On Wednesday, the facing of the pier, about seven feet from the ground, bulged out about three inches on the south side, and strained and bent the timber struts, which connected it with the north-west pier. The pier then settled down about three-quarters of an inch, crushing in the centre, in such a manner, that, on its north face, at about four feet from the ground, the front of the stones stood at their original height and perfect, while the back part of the same stones was crushed and pressed downwards three-quarters of an inch. On Thursday morning, the upper part of the pier was found cracked, and audibly cracking in many directions, flaked stones fell from it, whole stones burst out and fell. Finally, at half-past one, the whole gave way, as above related. (Willis 1861, xviii–xix)

This is not the place to discuss the repercussions of the collapse, or the rebuilding of the tower and spire by G.G. Scott in 1861–65 (for this, see Hobbs 1994 and Foster 2001). However, it is perhaps worth looking briefly at the

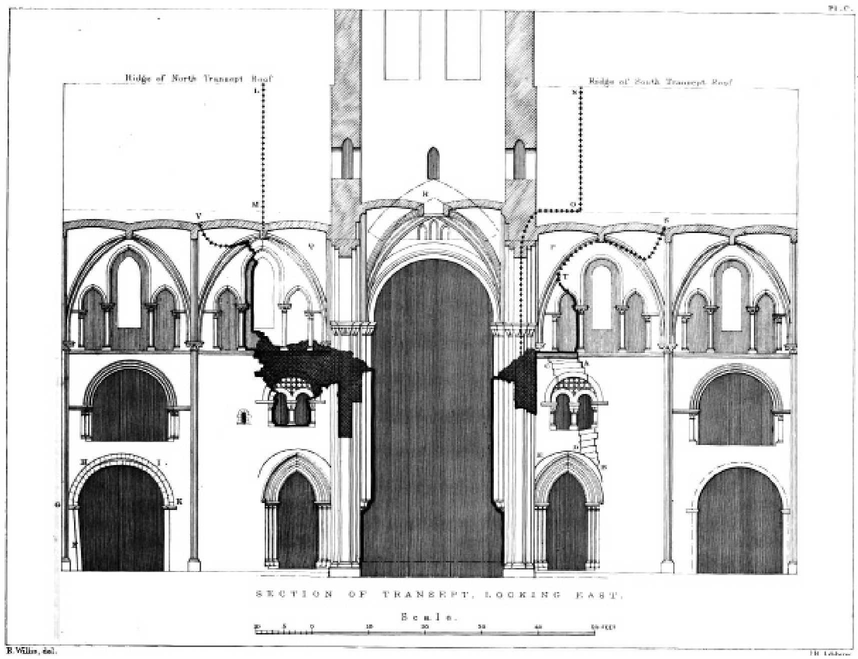


Figure 2
Section of transept looking east (Willis 1861, Plate C)

building and structure history of Chichester Cathedral to show how Willis's pioneering analysis of 1853 led directly to our recording work and analysis of the early 1990s. (For a fuller discussion of this, see Tatton-Brown in Hobbs 1994 and Tatton-Brown and Munby 1996, 47–55). A very good general architectural history (Godfrey and Bloe 1935) had, however, already appeared in the Victoria County History of Sussex before the Second World War.

Unlike at Canterbury, there was very little documentary evidence for Willis to study at Chichester. He did, however, manage to discover quickly that there are four principle phases of work at the cathedral, and he then goes on to discuss and elucidate mainly the first two phases. His phases are:

(a) The Norman Cathedral
(b) Works consequent on the fire of 1186 (the fire was actually on 20th October 1187)
(c) The 13th century addition of chapels (and porches) to the north and south of the nave
(d) 14th century and later additions to the cathedral (including the Lady Chapel and the tower and spire) and various rebuildings, particularly the north and south transepts.

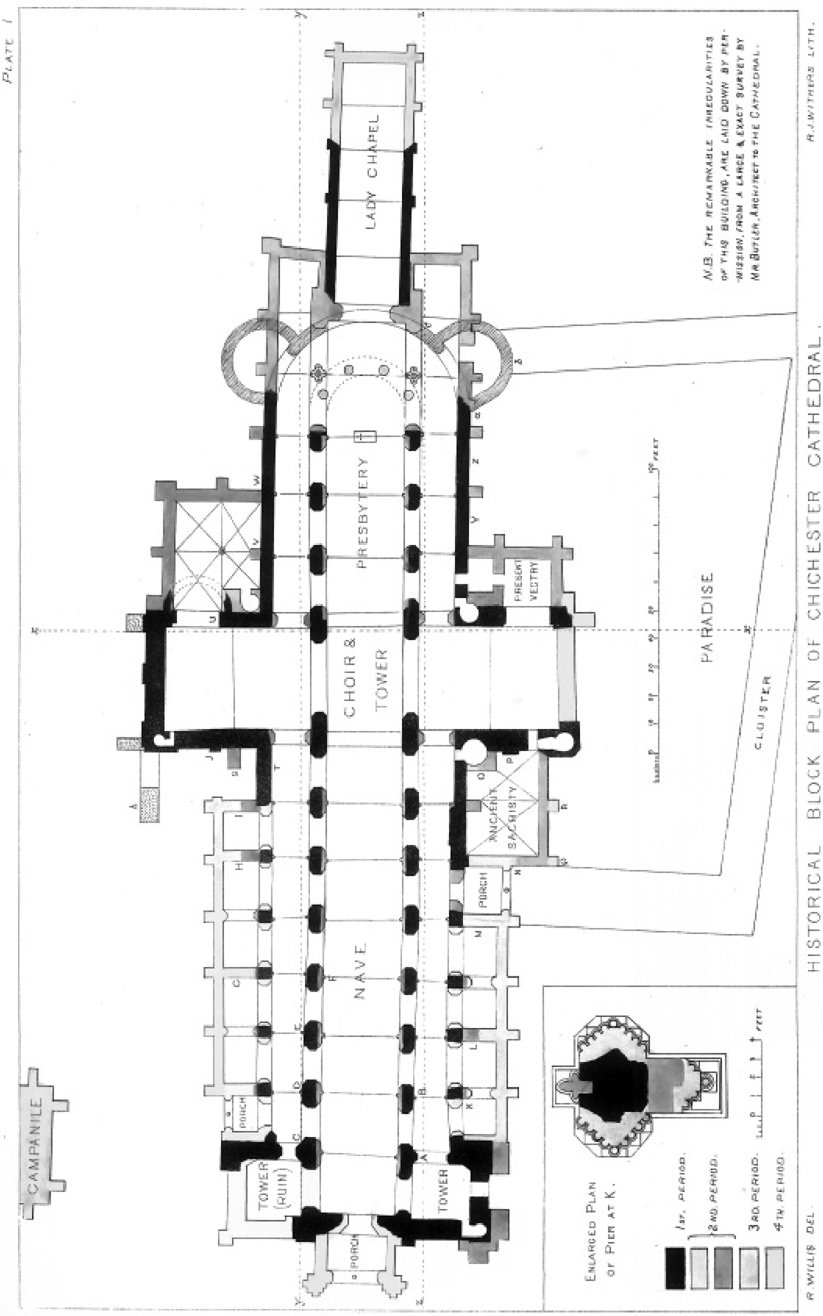


Figure 3
Historical block plan of the cathedral (Willis 1861, Plate 1)

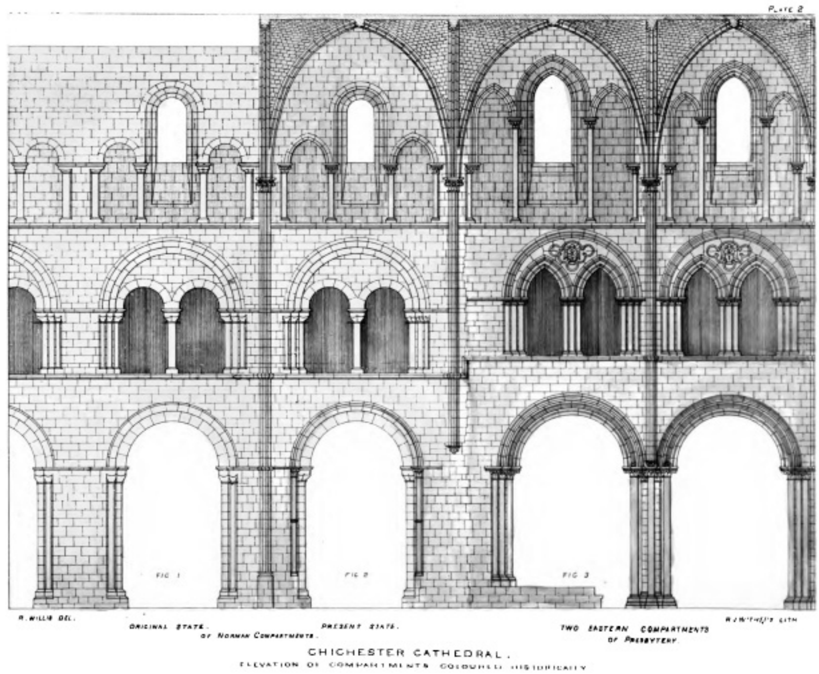


Figure 4
Elevation of three compartments (Willis 1861, Plate 2)

His analysis of the Romanesque cathedral, which was built in the old Roman walled city of Chichester from *c.*1076, is exemplary. Willis even managed to deduce that there had originally been semi-circular flanking chapels to the eastern ambulatory. The foundations to these chapels were subsequently found in 1960s rescue excavations. He also showed that the western end of the nave was only completed, after a pause in the work, in the early 12th century.

After a very serious fire on 20 October 1187, which burnt the cathedral and much of the city, Robert Willis showed brilliantly that a total rebuilding was not undertaken, but instead, the most severely calcined areas of masonry were refaced in Caen stone. At the eastern end of the cathedral, however, the old ambulatory was demolished, and a new more magnificent presbytery was started, using fine new compound piers of Purbeck marble, with superbly-carved large Corinthian capitals. These clearly reflect what was happening on a much larger scale at Canterbury and Lincoln cathedrals. Also at this time, quadripartite rib-vaulting was introduced to the whole cathedral, both in the high-vaults and in the aisles. The work was clearly interrupted by the infamous interdict (of 1207–15)

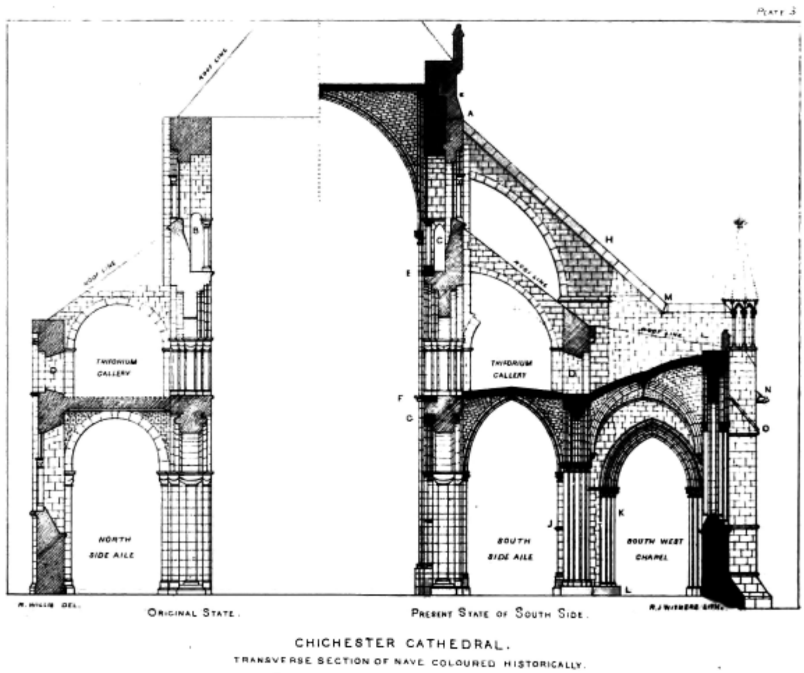


Figure 5
Transverse section of the nave (Willis 1861, Plate 3)

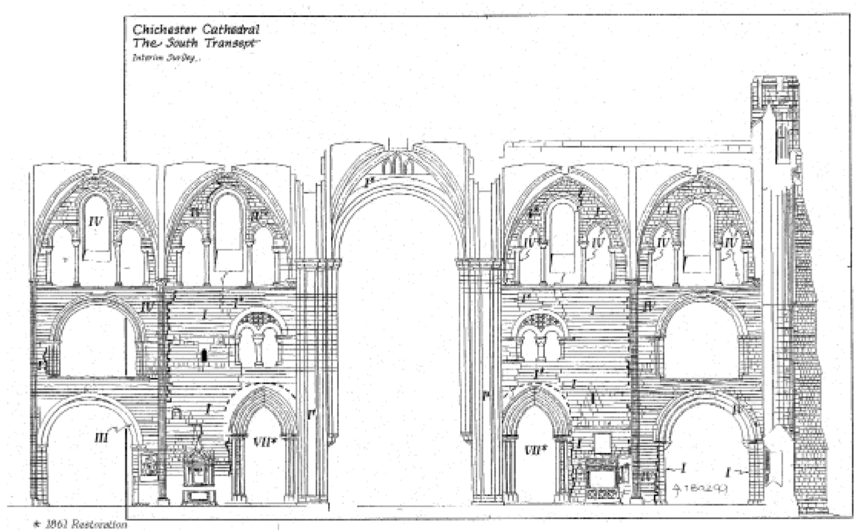


Figure 6
Chichester Cathedral. The South Transsept (Tatton-Brown)

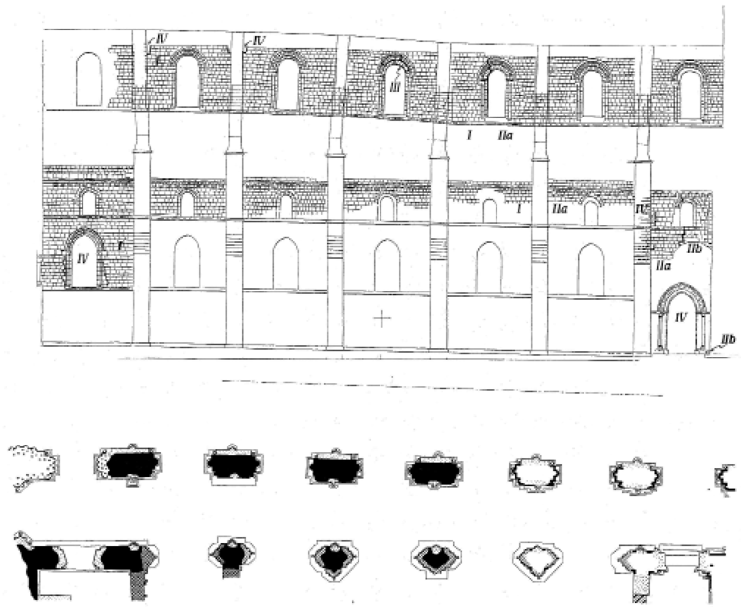


Figure 7
Chichester Cathedral. North Nave, showing 11th and 12th Cent. fabric (Jill Atherton, April 1995)

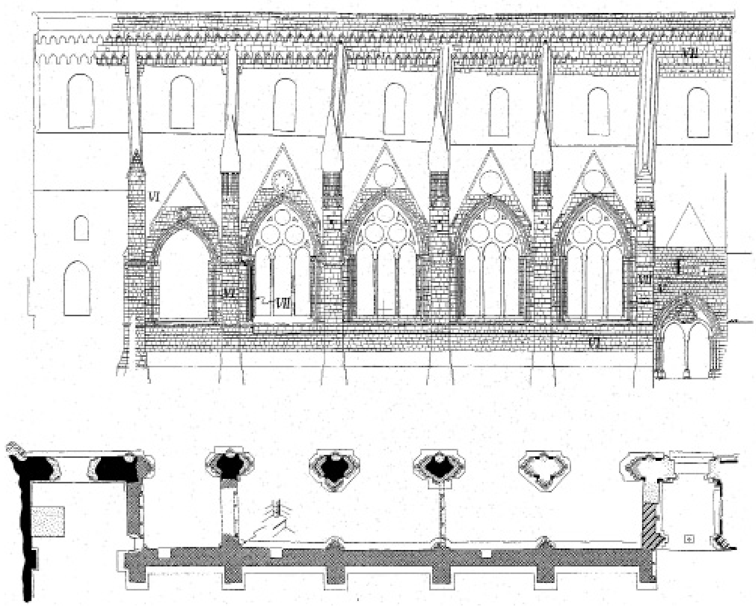


Figure 8
Chichester Cathedral. North Nave, showing 13th Cent. fabric (Jill Atherton, April 1995)

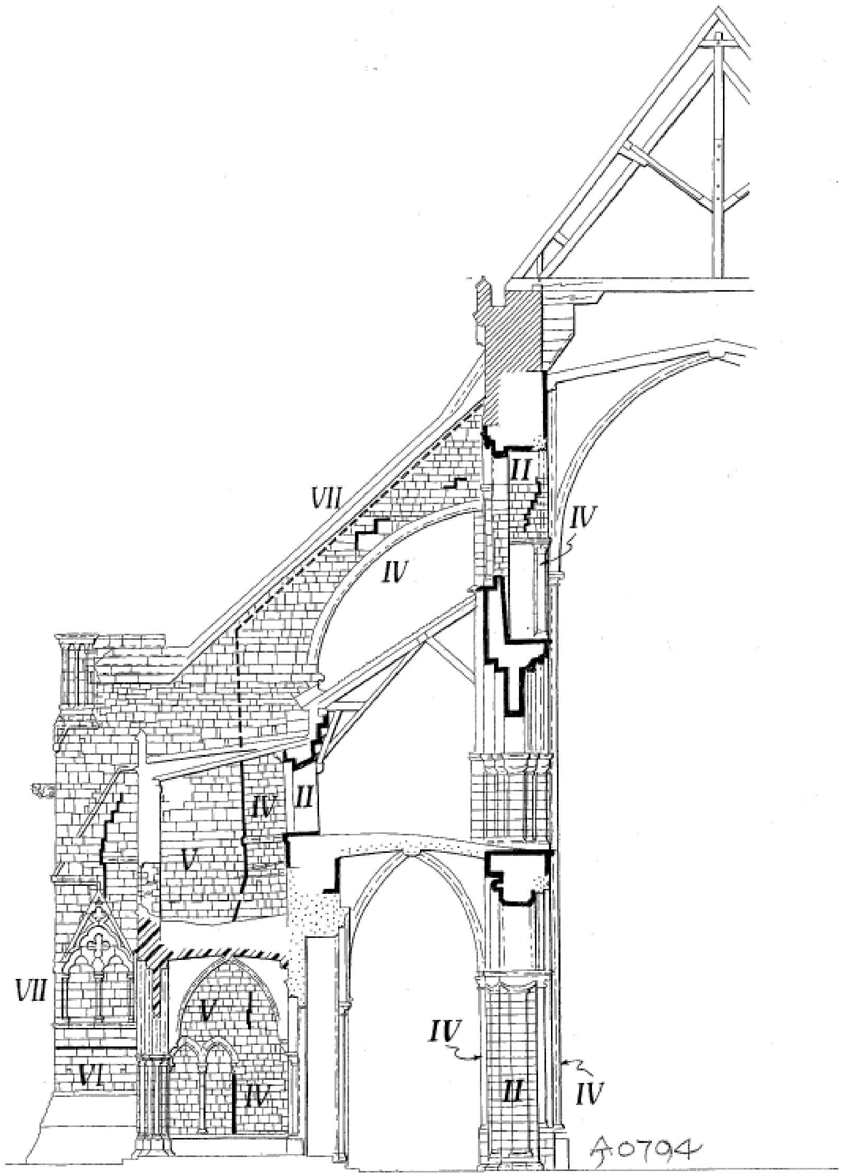


Figure 9
Phased section through the north porch and north side of the nave showing late eleventh (II) to late thirteenth (VII) century phases

during King John's reign, and by the partial collapse of the western towers in 1210. However, work continued after 1215, under Bishop Richard Poore, and was probably completed in the 1230s under Bishop Ralph Neville, the royal chancellor. Bishop Poore moved on to Salisbury in 1217, where he managed to start the building of an enormous new cathedral on a totally new site). This cathedral also had three eastern chapels, nut on a much larger scale. The east end of Chichester Cathedral was, therefore, in part, a prototype for Salisbury.

All the other phases of new masonry observed by Willis will not be discussed here, but it is of interest to note that in his last two pages Willis used the architect Joseph Butler's measured plan of the cathedral to discuss, very briefly, the structural history of the building. As is now well-known, Chichester Cathedral was built over the remains of many demolished urban Roman buildings. An intact Roman mosaic pavement was even found beneath the south presbytery aisle. Also the remains of some of these buildings must have been used as rubble in the Romanesque walls. As a result of this Chichester Cathedral (like its great neighbour at Winchester) had very uneven foundations, which suffered from differential settlement, almost as soon as the walls started to be built. Willis briefly lists all the main irregularities in the settling out of the different parts of the building, and then goes on to point out all the irregularities in the surviving walls, that lead, at the end of the 13th century, to completely new heightened upper walls with flying buttress being built. The tops of the Romanesque nave walls are still there, and bow-shaped in plan, while the new *c.* 1300 masonry above is still stable and straight. Remarkably the new roof that was put on at this time still exists, though now covered in copper, rather than lead! The rebuilding, and later stability of upper walls of the main vessels (nave and presbytery), was greatly helped by the adding of outer chapels (in the "French Gothic" manner) earlier in the 13th century. Willis's transverse section of the nave in 1853 shows all this very clearly. It also shows all the refacing with the new masonry after the 1187 fire. Our new recording work, in the late 1980s, managed to build on this, and show more sub-phases of the work. We were also able to rediscover the original rain-water disposal system from the high roof.

A new "point-cloud" digital survey of Chichester Cathedral should now be able to show the complete structural settlement history of the building from *c.* 1076 to 1861, once all the masonry has been recorded and analysed. It should also be able to show, in much more detail, the events leading up to the failure of the south-west crossing pier in 1861. As well as this, it will be interesting to see what movement has taken place since Scott's massively strong rebuilding of the tower and spire. Also how stable is the building half a century after Robert Potter's underpinning work, and introduction of reinforced concrete in the upper walls.

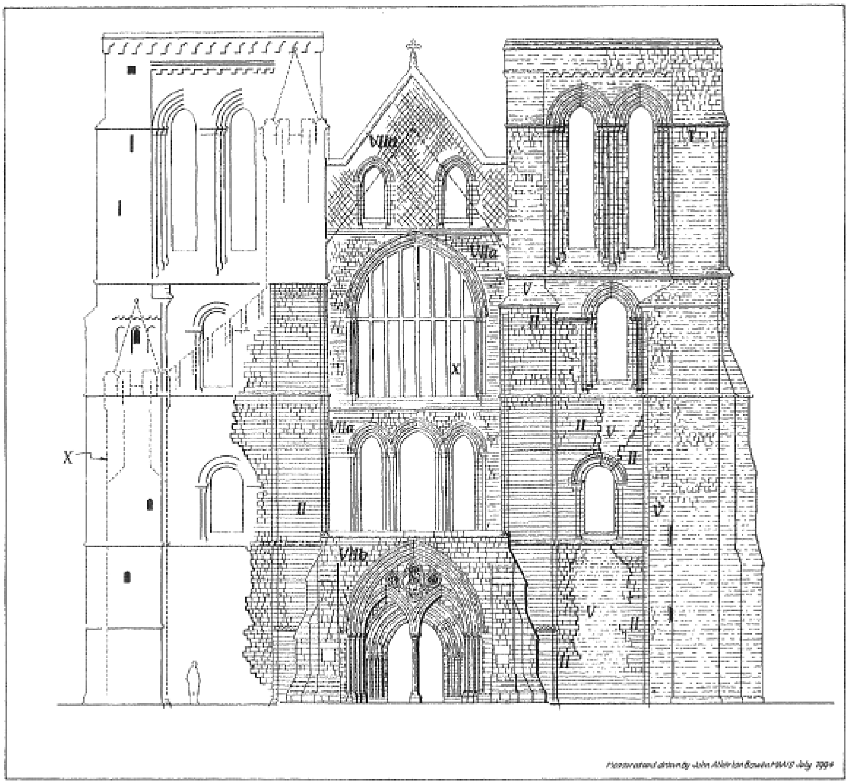


Figure 10
Sketch elevation and provisional phasing of the masonry of the west front, showing late eleventh (II) to late thirteenth (VII) century phases

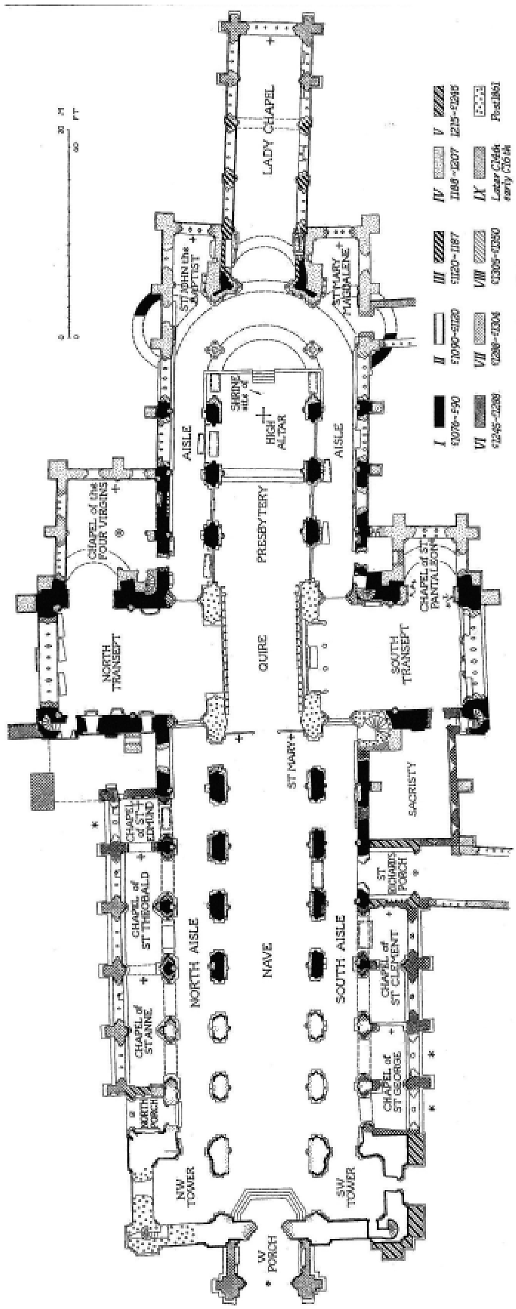


Figure 11

New phased plan of the main constructional phases of Chichester Cathedral (Tatton Brown, Atherton)

Reference List

Collinson, Patrick; Ramsay, Nigel and Sparks, Margaret eds. 1995. *A History of Canterbury Cathedral.* Oxford: Oxford University Press.

Foster, Paul ed. 2001. *Chichester Cathedral Spire: The Collapse (1868).* Chichester: University College Chichester.

Gibson, Margaret; Heslop, T.A. and Pfaff, Richard W. eds. 1992. *The Eadine Psalter.* London: Pennsylvania State University Press.

Godfrey, Walter H. and Bloe, J.W. 1935. *Victoria History of the County of Sussex III,* 105 – 160.

Hobbs, Mary ed. 1994. *Chichester Cathedral, an Historical Survey.* Chichester: Phillimore.

Pevsner, Nikolaus 1970. *Robert Willis.* Northampton, Mass: Smith College.

Pevsner, Nikolaus and Metcalf, Priscilla 1985. *The Cathedrals of England* (2 Vols.). Harmondsworth: Penguin.

St. John Hope, W.H. 1900. *The Architectural history of the Cathedral Church and Monastery of St. Andrew at Rochester.* London: Mitchell and Hughes.

Sparks, Margaret 2007. *Canterbury Cathedral Precincts, A Historical Survey.* Canterbury: Dean and Chapter of Canterbury.

Tatton-Brown, Tim 1983. The Precincts Water Supply. *Canterbury Cathedral Chronicle* 77: 45–52.

Tatton-Brown, Tim 1984. Three Great Benedictine Houses in Kent: their Buildings and Topography. *Archaeologia Cantiana* 100: 171–188.

Tatton-Brown, Tim 1989. *Great Cathedrals of Britain, an Archaeological history.* London: BBC Books.

Tatton-Brown, Tim and Munby, Julian eds. 1996. *The Archaeology of Cathedrals.* Oxford: Oxford Committee for Archaeology.

Willis, Robert 1845. *The Architectural History of Canterbury Cathedral.* London: Longman.

Willis, Robert 1861. *The Architectural History of Chichester Cathedral.* Chichester: William Hayley Mason.

Willis, Robert 1868. The Architectural History of the Conventual Buildings of the Monastery of Christ Church in Canterbury. *Archaeologia Cantiana* 7: 1–206.

Drawing proofs: lo sguardo cinematico di Robert Willis

Antonio Becchi

L'ingrato destino dell'ingegnere

Nell'ormai plurisecolare dibattito sull'*arte del costruire* e, quindi, sul ruolo e sulla formazione di ingegneri e architetti, un particolare risulta ricorrente: al contrario degli architetti, gli ingegneri edili sono di solito ricordati e ammirati per quello che non si vede, per quello che sta dentro, sotto, sopra, per quello che, in generale, è costruito dietro le quinte, dove le quinte sono disegnate da artisti, designers, architetti. L'ingegnere lavora per qualcosa che deve funzionare bene, durare nel tempo, resistere agli sforzi: l'aspetto estetico può svolgere un ruolo, ma raramente è considerato essenziale. Talvolta si può semmai ricevere un riconoscimento postumo in nome del *Reason's eye*, come ricorda William John Macquorn Rankine nella *Preliminary Dissertation on the Harmony of Theory and Practice in Mechanics* —inizialmente preparata come conferenza in latino dal titolo *De Concordia inter Scientiarum Machinalium Contemplationem et Usum*— del suo *Manual of Applied Mechanics* (1858):

> For a century there has stood, in a room in this College, a small, rude, and plain model, of appearance so uncouth, that when an artist lately introduced its likeness into a historical painting, those who saw the likeness, and knew nothing of the original, wondered what the artist meant by painting an object so unattractive. But the artist was right; for ninety-one years ago a man took that model, applied to it his knowledge of natural laws, and made it into the first of those steam engines that now cover the land and the sea; and ever since, in Reason's eye, that small and uncouth mass of wood and

> metal shines with imperishable beauty, as the earliest embodiment of the genius of James Watt. (Rankine 1858, 11)

Naturalmente vi sono molti ingegneri che progettano o hanno progettato strutture di grande qualità *architettonica*, già esaltate da Le Corbusier nel celebre testo-manifesto *Vers une architecture* (1923): "Esthétique de l'ingénieur, Architecture, deux choses solidaires, consécutives, l'une en plein épanouissement, l'autre en pénible régression" (Le Corbusier 1923, 3). Quelle eccezioni, tuttavia, non possono far dimenticare una distinzione dei ruoli profondamente radicata nella mentalità del grande pubblico e, molto spesso, degli stessi addetti ai lavori. Una mentalità e un comune sentire che *Vers une architecture* rivela nelle carambole interpretative che ne contraddistinguono la narrazione. Se l'ingegnere si occupa anche degli aspetti estetici dell'opera da costruire, allora diventa designer (auto, imbarcazioni etc.) o ingegnere-architetto (ponti, grattacieli, grandi coperture etc.). Figure come quelle di Robert Maillart, Pier Luigi Nervi, Ove Arup e tante altre sono esaltate dalla critica in quanto casi particolari, che di solito confermano vecchie certezze piuttosto che sollecitare nuove riflessioni.

Questa divisione, fondata su fattori di immediato impatto visivo, è tutt'altro che scontata. Essa prevede una precisa distinzione delle competenze, che affonda le sue radici in un'altrettanto precisa, per quanto assai traballante, concezione dell'arte e del bello. Le opere degli ingegneri sono talvolta additate come esemplari anche dal punto di vista *artistico*, ma in quel riconoscimento si nasconde sempre, almeno dall'Ottocento in poi, una certezza più o meno dichiarata: la bellezza non è tema specifico da ingegnere, così come non lo è la storia. La dimostrazione si ha nei corsi universitari attuali, dove agli ingegneri non viene richiesto, salvo rare e felici eccezioni, di imparare i rudimenti dell'arte e della storiografia: quelle materie vengono considerate superflue nella formazione di un buon *engineer*, che deve invece concentrarsi sull'efficienza, sul presente e, se possibile, soprattutto sul futuro, senza perdere tempo con argomenti che non gli competono.

Willis e le due sorelle

Tra gli studiosi di meccanica e di architettura che si sono sottratti a questo destino, rimanendo associati a opere *esteticamente* ben note al pubblico degli specialisti, Robert Willis rappresenta un caso particolare (Buchanan 2013). Dal 1838 membro onorario dell'*Institution of Civil Engineers*, vincitore della *Royal Gold Medal* del *Royal Institute of British Architects* nel 1862 (la stessa medaglia assegnata nel 1864 a Eugène Viollet-le-Duc e nel 1904 ad Auguste Choisy), la sua formazione è certamente più simile a quella di un esperto di meccanica che a

quella di un architetto. Willis si occupa per decenni di cattedrali gotiche, ma nel contempo insegna meccanica applicata all'Università di Cambridge (in seguito anche alla *Royal School of Mines* di Londra) e pubblica un volume, *Principles of mechanism* (Willis 1841), che lascia il segno a livello internazionale, come lui stesso sottolinea con orgoglio nella seconda edizione di quell'opera (Willis 1870, xx). L'esperienza nel campo della meccanica applicata, inoltre, gli consente di essere nominato membro della *Royal Commission* istituita il 27 Agosto 1847 (dopo un acceso dibattito seguito all'incidente del *Dee bridge* del 24 Maggio 1847), che due anni dopo pubblica un fondamentale rapporto sull'*Application of Iron to Railway Structures* (Report 1849). Willis viene inoltre coinvolto come *Juror* nella *Great Exhibition* del 1851, occupandosi, in particolare, di *Machines and Tools for Working in Metal, Wood, and Other Materials* (Willis 1852) e nel 1855 ricopre il ruolo di vice-presidente dell'esposizione universale di Parigi. Nel ricordo-necrologio apparso nei *Minutes of Proceedings of the Institution of Civil Engineers* il suo contributo tra ingegneria e architettura viene chiaramente definito a favore della seconda: "But great as is the indebtedness of the engineering profession to Professor Willis, it is far less than that of its elder sister, Architecture; and it is as an investigator into the architectural history of individual ancient buildings that his reputation will live, when the memory of his achievements in mechanical science may have faded." (Minutes 1875, 208)

Le immagini architettoniche che hanno reso celebre Willis non sono legate a grandi progetti o a strutture di particolare audacia statico-costruttiva. La sua fama è soprattutto fatta di carta, confinata alle parole e alle rappresentazioni ad esse allegate. I disegni più celebri, quelli che da allora sono sempre associati al suo nome, sono presentati in tre sole tavole e rinviano a strutture nascoste, a dettagli costruttivi che sino ad allora non erano entrati negli album degli architetti e che nel seguito ne diventeranno parte integrante (almeno di quelli più colti). In questo senso la sapienza *nascosta*, il *sapere murato* racchiuso nella fabbrica architettonica, torna alla ribalta come caratteristica dell'ingegnere, che nel caso di Willis trova una levatrice d'eccezione.

Le immagini alle quali si fa sempre riferimento sono note: pubblicate per la prima volta nel saggio *On the Construction of the Vaults of the Middle Ages* (Willis 1842), esse descrivono la *Fan Vault, East End of Peterborough Cathedral* (Fig. 1), la *Vault of Henry the Seventh's Chapel Westminster* (Fig. 2) e la *Vault of St. George's Chapel at Windsor* (Fig. 3).

La data della pubblicazione non può passare inosservata: siamo nel 1842, l'anno precedente era uscita la prima edizione dei *Principles of mechanism* (1841). Willis aveva allora 42 anni, dal 1837–38 era *Jacksonian Professor of Natural and Experimental Philosophy* all'Università di Cambridge, in sostituzione di William Farish, morto nel 1837. Le due opere monografiche nascono qua-

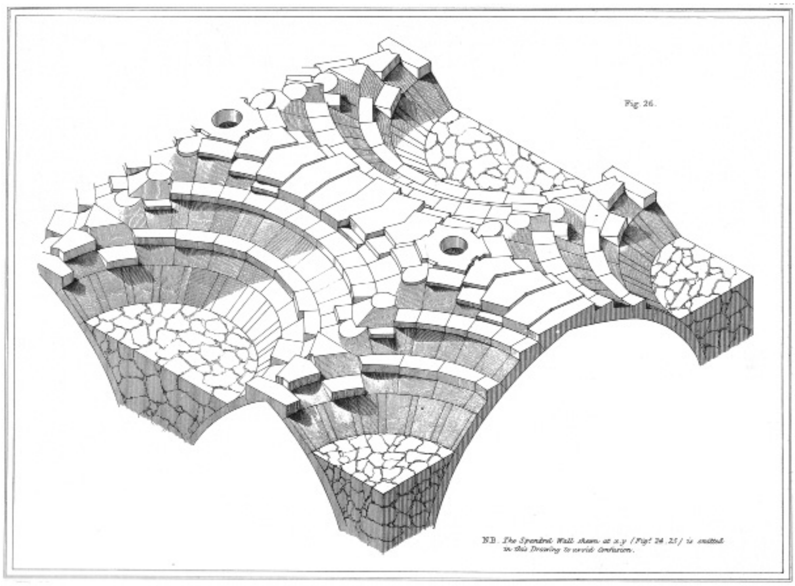


Figure 1
Fan Vault, East End of Peterborough Cathedral (Willis 1842, Plate II)

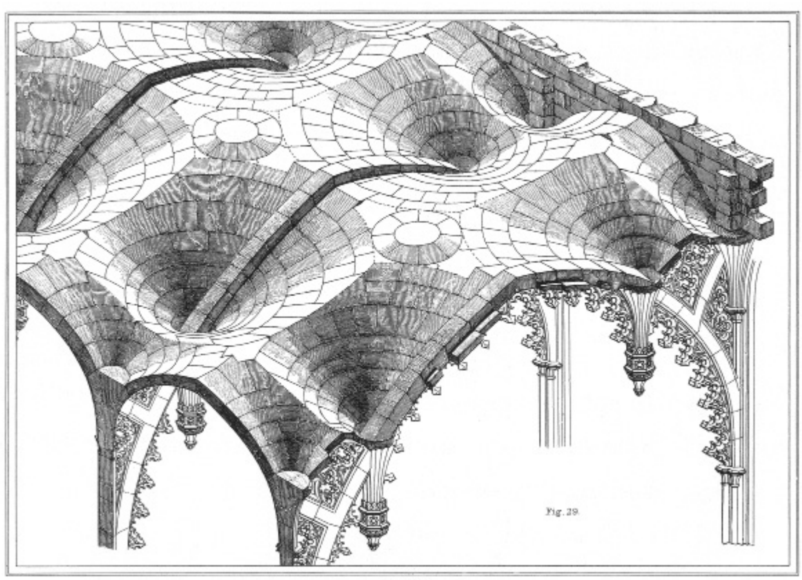


Figure 2
Vault of Henry the Seventh's Chapel Westminster (Willis 1842, Plate III)

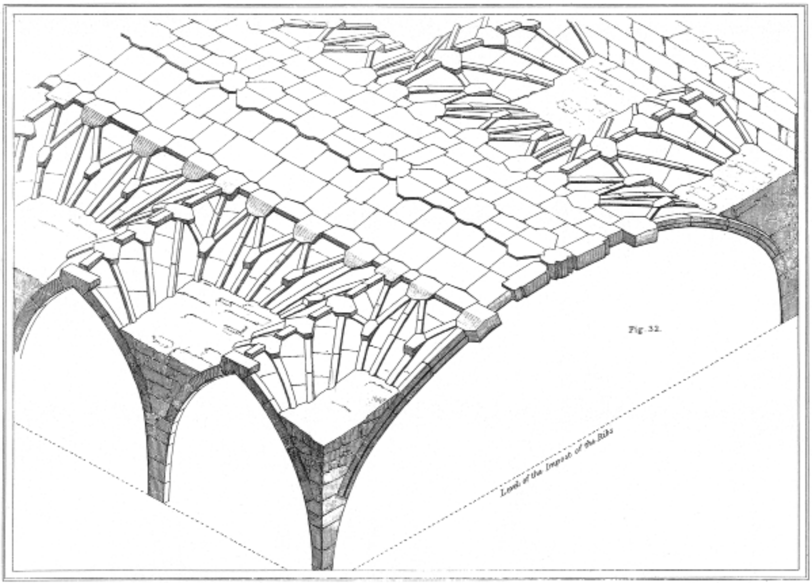


Figure 3
Vault of St. George's Chapel at Windsor (Willis 1842, Plate IV)

si contemporaneamente e, pur affrontando temi diversi, sono simili e come tali devono essere lette. Un'ulteriore parallelismo può stabilirsi con il trattato di William Whewell *The mechanics of engineering* (Whewell 1841), come dichiarato esplicitamente dai due autori, amici e colleghi nella stessa università (Marsden 2004). La prefazione di Whewell al suo trattato, nella quale si spiega che il sapere ingegneristico è rivolto a tutti e dovrebbe far parte della *general education*, può servire da introduzione all'opera di Willis:

> The relations of space once learnt in geometry do not fade away from our thoughts, because throughout our lives we continue familiar with exemplifications of them in Geography, Astronomy, and other common pursuits. If the common Problems of Engineering were to form part of our general teaching in Mechanics, this science also might become a permanent possession of liberally educated minds. Every roof, frame, bridge, oblique arch, machine, steam-engine, locomotive, carriage, might be looked upon as a case to which every well-educated man ought to be able to apply definite and certain principles in order to judge of its structure and working. And this would, I conceive, be an improvement, not only in professional, but in general education. (Whewell 1841, vi)

La fama delle immagini di Willis appena menzionate è fuori discussione e una prova si ha nella riproduzione di un particolare di esse sulla copertina della bella monografia di Alexandrina Buchanan (Buchanan 2013), così come nella pagina internet del *Robert Willis Symposium*. Sin dal momento della loro prima circolazione ad esse è riconosciuta una forte originalità, benché il disegno d'architettura avesse, all'epoca, secoli di storia alle spalle. Nell'Ottocento, inoltre, le pubblicazioni sul tema si erano moltiplicate e l'interesse per l'architettura gotica era tale che volte, archi, pinnacoli e portali erano diventati oggetti di una diffusione vasta e capillare. La concorrenza era dunque forte, al massimo livello, ma nonostante questo le tavole di Willis risultarono alla maggior parte dei contemporanei fuori dal comune. È necessario allora chiarire le ragioni che hanno trasformato quelle immagini, pubblicate da un autore sino ad allora non particolarmente noto per i suoi disegni o per i suoi studi di architettura, in un punto di svolta. Occorre comprendere perché esse suscitarono allora tanto interesse e perché ancora oggi sono considerate esemplari: per quale ragione quei disegni spiazzano l'osservatore e lo costringono a ripensare la sua idea di architettura? È sufficiente notare, come è stato fatto da John Willis Clark in un passo più volte citato dagli studiosi successivi, che "He treated a building as he treated a machine: he took it to pieces" (Clark 1890, 22)?

Vengono spesso sottolineati aspetti della biografia di Willis che all'apparenza risultano bizzarri e sembrano giustificare un'attenzione inusuale per il dettaglio meccanico e costruttivo: dalle indagini sul presunto automa che giocava a scacchi (Willis 1821), agli studi sulla meccanica della laringe (Willis 1833), passando per le ricerche *On the Teeth of Wheels* (Willis 1838). Tutti aspetti significativi, ma non certo singolari nel panorama degli studiosi fioriti tra XVIII e XIX secolo. A questo proposito si possono trovare analogie un po' ovunque in Europa, a partire almeno da Philippe de La Hire (La Hire 2013), anche lui *outsider* e *géomètre* appassionato di volte e di macchine, con interessi che spaziavano dalla meccanica teorica allo studio del movimento della lingua del picchio, dall'idraulica alla forma degli ingranaggi (contributi che, almeno in parte, Willis studiò con attenzione e che forse lo influenzarono al di là di quanto sino ad oggi è stato appurato). Gli interessi di Willis erano in linea con una certa idea di scienziato a tutto campo, rinvigorita, nel corso dell'Ottocento, dalla corsa alle *invenzioni* e dalla consapevolezza che l'ingegno, allenato da un'educazione liberale che a Cambridge aveva una solida tradizione, poteva e doveva applicarsi in qualsiasi campo, per guidare e rafforzare lo sviluppo industriale.

Il carattere multiforme degli interessi di Willis non può dunque spiegare in profondità il tratto sorprendente di quelle rappresentazioni, così singolari e suggestive. Bisogna approfondire meglio l'origine della meraviglia che esse suscitano, descritta con grande vivezza da Auguste Choisy in occasione del conferimento della *Royal Gold Medal* del *Royal Institute of British Architects*:

> Presque enfant, en feuilletant les livres de la bibliothèque de mon père, j'eus la bonne fortune de rencontrer le Mémoire du Révérend Robert Willis sur les voûtes du moyen âge. Ce fut une révélation: C'est ainsi, me dis-je, que les formes doivent être analysées; c'est ainsi que le dessin doit exprimer la structure. Et, lorsque j'essayai de résumer les procédés romains, j'eus sans cesse présent comme un modèle de méthode ce mémoire sans précédent, qui marque à la fois les débuts et le dernier terme de la critique architecturale. (Choisy 1904, 452)

Per comprendere il potere folgorante, quasi sciamanico, di quelle tavole occorre provare a cogliere le differenze con analoghe rappresentazioni che le avevano precedute. Si può notare, ad esempio, che archi e volte erano di solito disegnati dal basso, talvolta a distanza ravvicinata grazie all'uso di scale o ponteggi. Le volte viste dall'alto non erano una visione usuale, anche se alcuni casi significativi erano noti. Le tavole di Johann Jacob Schübler (Schübler 1732, Tav. X; Fig. 4), ad esempio, proponevano un punto di vista non dissimile, anche se applicato a tutt'altro contesto.

Le immagini del saggio *On the Construction of the Vaults of the Middle Ages*, tuttavia, risultano profondamente diverse. Esse mostrano una particolare visione interna che certamente deriva dalla passione archeologica di Willis, secondo il quale:

> Next to complete buildings under repair, Ruins afford the most valuable information upon construction. The best instructor of all, perhaps, is a building which is being pulled down, but such opportunities are always to be regretted. In ordinary cases, the upper surfaces of the vaults are so often covered with courses of rubble and concrete, rubbish and filth, and the lower surfaces with whitewash and paint, that when every facility has been obtained for examination, the jointing of the masonry and actual construction of the vault will still remain an unfathomable mystery. (Willis 1842, 3)

Nel tipo di rappresentazione scelto da Willis, inoltre, si coglie la capacità sviluppata dal disegnatore di macchine: la *isometric perspective* consente di mostrare in un unico disegno tutte le parti, di renderle immediatamente misurabili, di cogliere ogni singolo dettaglio, lasciando così la possibilità all'osservatore di comprendere al meglio la concatenazione degli elementi e il funzionamento del meccanismo. Farish aveva sottolineato come l'*isometric perspective* potesse rivelare "what is hid in nature" (Farish 1822, 14), Willis ne aveva colto la lezione trasferendola all'architettura, *grande macchina* per eccellenza.

I disegni delle volte di Petersborough, Windsor e Westminster mostrano quello che di solito è nascosto alla vista. L'architetto, o chi per lui, che aveva immaginato la costruzione, non pensava che quelle parti diventassero oggetto di

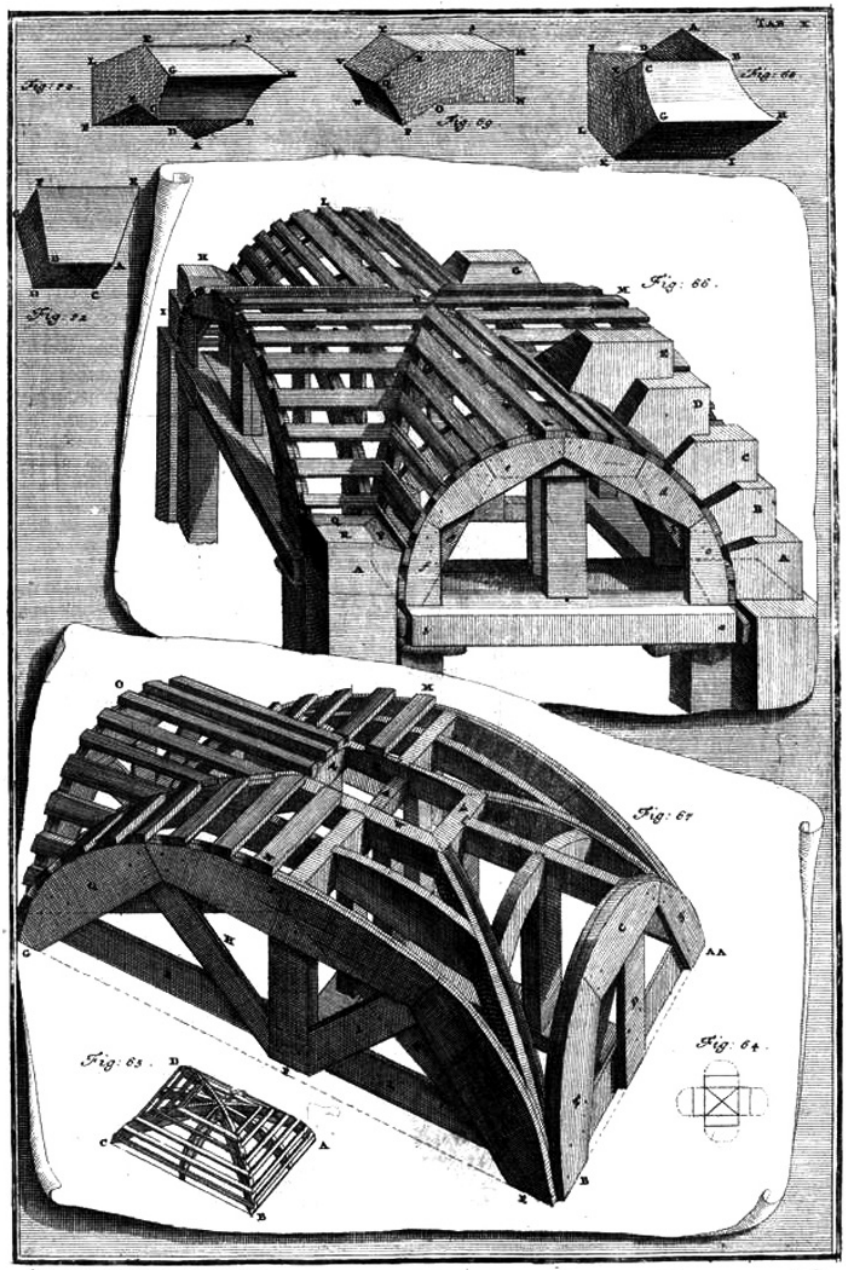


Figure 4
Centine in un'immagine della *Synopsis Architecturae Civilis Eclecticae* di Johann Jacob Schübler (Schübler 1732, Tav. X)

studio e di contemplazione. Si disvela, quindi, quello che non era pensato per lo spettatore, e lo si rappresenta sul foglio di carta con strumenti geometrici assai più efficaci di quelli che Willis aveva impiegato anni prima per raffigurare la scatola magica usata dal misterioso giocatore di scacchi (Willis 1821). Molta strada aveva fatto Willis da quei primi esercizi giovanili e la geometria era diventata il naturale complemento della meccanica, come spiega lui stesso nella *Lecture* dedicata ai risultati della *Great Exhibition* del 1851, dopo aver parlato dell'"unfortunate boundary wall or separation between practical and scientific men":

> In no department of science is this carried to a greater extent than between the mathematical and practical mechanics; and yet the mental process by which the parts of a complex machine are contrived and arranged in the brain of the inventor requires the geometrical faculty, as it is called, to a very high extent: that is to say, the power of conceiving mentally the relations of the parts of complex figures in space. So that, in truth, a man gifted by Nature as a mechanist is also qualified as a geometrician (…). (Willis 1852, 297)

L'operazione messa in mostra nelle tavole di Willis è squisitamente geometrico-archeologica e si avvale di quel particolare tipo di rappresentazione come necessario strumento di indagine: chi scava va alla ricerca di quello che non si vede e tira fuori dagli armadi della storia quello che è nascosto o è difficilmente intelligibile (perché ridotto in parti, perché scomposto, perché inglobato nel terreno o nei fondali marini). All'archeologo interessa tutto, ogni dettaglio, ogni particolare che consenta di ricostruire quello che è stato smembrato e distrutto dall'incuria e dal tempo. In questa prospettiva i disegni di Willis devono associarsi a tanti altri, anche se la rappresentazione assonometrica e la chiarezza del dettaglio possono essere considerati fuori dal comune. Il confronto più eclatante è fornito dall'opera di Giovanni Battista Piranesi. Nei disegni e nelle incisioni dell'artista veneto gran parte del fascino costruttivo risiede nella messa in mostra delle parti nascoste dei monumenti antichi (fondazioni, vani nascosti sotto le coperture). È infatti proprio una tavola di Piranesi che fa capire lo scarto tra le immagini di Willis e quelle che le avevano precedute e, in parte, le seguiranno. In essa si mostra un dettaglio della cupola del Pantheon, disegnato da Giovanni Battista Piranesi e poi pubblicato da suo figlio Francesco (Piranesi 1790, Tav. XXVIII; Fig. 5). L'immagine è straordinaria e sembra rivelare una volta per tutte i segreti di quel monumento diventato simbolo della romanità e della sapienza costruttiva sviluppata nell'Antichità.

Per rimarcare il carattere *documentario* della raffigurazione, nella nota che accompagna l'incisione Piranesi scrive "come si vidde, quando fù spogliata

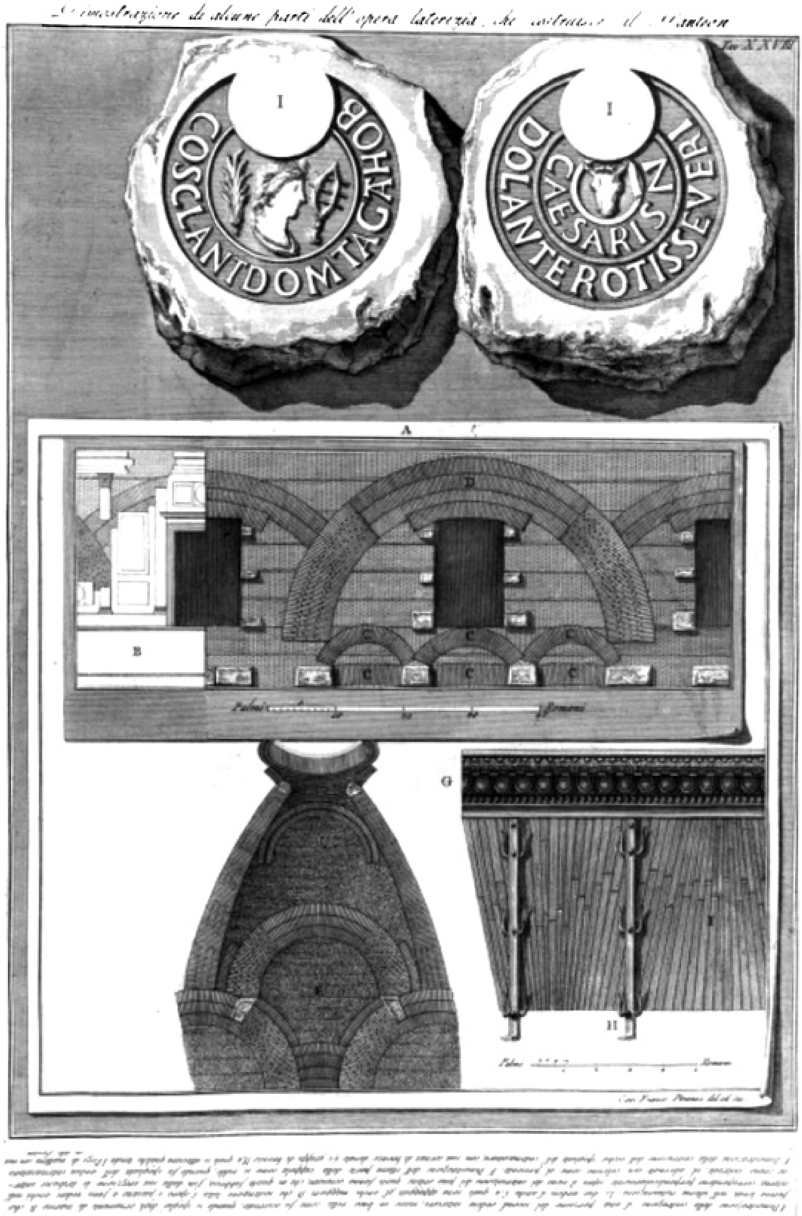


Figure 5
Vista interna della cupola del Pantheon secondo Giovanni Battista Piranesi (Piranesi 1790, Tav. XXVIII)

dell'antica intonacatura" (Piranesi 1790, Tav. XXVIII), come se si trattasse di testimonianza oculare. Nel caso di quel dettaglio costruttivo si tratta, tuttavia, in gran parte d'invenzione. Alcuni di quegli archi che l'immagine raffigura (incisione in basso a sinistra della Fig. 5, "ottava parte della cuppola"), così ben disposti e conformati, nella realtà non esistono, come ha potuto constatare Luca Beltrami alla fine dell'Ottocento e hanno confermato ulteriori indagini (Beltrami 1898, in particolare 22–27; Martines 2015). Il desiderio di mettere in vista, di scoprire i segreti della costruzione, di mettere a nudo e radiografare l'interno degli edifici, porta Piranesi a dichiarare e disegnare il falso. Non solo: quel falso risulta così seducente e convincente che finisce per annebbiare gli occhi e la mente di molti studiosi, che lo assumono frettolosamente come fosse vero, felici di poter finalmente dimostrare la *razionalità* dell'architettura romana, la capacità di conformare la struttura secondo *linee di forza*. Una falsa prova usata a più riprese, anche recentemente, per dimostrare la validità di una lettura ideologica dell'architettura e della sua evoluzione.

L'archeologia si muove da sempre su questo incerto crinale che separa e unisce documentazione rigorosissima, quasi maniacale, di ogni frammento, e tentazione di interpretare il singolo elemento come parte di un tutto, da immaginare e ricostruire come un paleontologo ricostruisce un dinosauro sulla base di una serie sparsa di ossa (secondo la celebre lezione di Georges Cuvier). Nell'Ottocento qualcosa di analogo si sperimentava nella geologia (Willis lo sapeva bene, Whewell ancor meglio), dove le stratificazioni terrestri e le cavità dei vulcani erano oggetto di ricostruzioni talvolta fantasiose, spesso non meno azzardate di quelle che anni prima avevano portato a ricostruire con carta e penna la mitica arca di Noè. Non è un caso che Farish citi, tra le varie possibili applicazioni del metodo di rappresentazione da lui proposto, lo studio di un vaso etrusco e la descrizione degli strati geologici (Farish 1822, 14 e 17).

Willis non cede alla tentazione che ha sedotto Piranesi e lo ha spinto a piegare la realtà alla sua idea di architettura: egli si attiene quasi sempre ai fatti, ai documenti, a quello che vede. A proposito delle tavole III e IV (qui Fig. 2 e 3) del saggio *On the Construction of the Vaults of the Middle Ages* (1842) è spiegato che: "which also represents it as having some portions dissected away, to show better its relation to the great arch below" (Willis 1842, 54; Fig. 2); "which represents the upper surface of the vault, but is dissected at the sides and end to show the relation of the upper and lower surfaces" (Willis 1842, 59; Fig. 3). I suoi disegni non solo sorprendono perché inusuali, ma trasmettono immediatamente fiducia, danno l'idea di qualcosa che corrisponde al vero e non è frutto di immaginazione: "We are all of us aware that we must become masons as well as architects if we wish to understand these structures" (Willis 1972–1973, II, Minutes, 27). Non si tratta, quindi, di fantasiosa archeologia, desiderosa di comple-

tare, spiegare, mostrare in forma compiuta, ma di anatomia architettonica che si dedica alla dissezione con pazienza e rigore. Torna così in campo un vecchio parallelismo tra architettura e teatro anatomico, tra corpo della costruzione e corpo umano, sul quale Vitruvio e Leon Battista Alberti avevano scritto pagine memorabili e che in ambito archeologico, tra XVIII e XIX secolo, si era trasformato in operazione scientifica di scavo *in corpore vili.* Dall'attenzione al rapporto tra i singoli elementi e il tutto, alla ricerca di un'armonia basata sulle proporzioni, si era passati alla descrizione dei dettagli costruttivi di più difficile lettura, che di quell'armonia costituivano l'indispensabile sostanza materiale.

A questo proposito, nonostante l'accostamento che spesso è stato suggerito tra Willis e Choisy, additati come padri di un modo nuovo di intendere lo studio dell'architettura e della costruzione, si dovrebbero qui notare piuttosto le differenze. Le tre celebri tavole di Willis sono molto diverse, dal punto di vista visivo e programmatico, da quelle proposte a più riprese da Choisy: quest'ultimo privilegia lo 'sguardo della rana', dal basso verso l'alto, con volumi che si librano nell'aria e lo sguardo dello spettatore che li segue da terra, come seguirebbe il volo di una mongolfiera; le tavole di Willis, invece, propongono un punto di vista che prevede una disposizione opposta, con lo spettatore questa volta imbarcato su un'immaginaria navicella. Una rappresentazione, quest'ultima, che non insiste sui volumi architettonici che potrebbe apprezzare chi si concedesse una sotterranea *promenade architecturale* e si sofferma invece sulla trama costruttiva interna, che il normale fruitore dell'edificio non vede e non è normalmente invitato a vedere.

Come è noto anche Choisy presenta assonometrie dall'alto, molto probabilmente seguendo la lezione di Willis, ma raramente lo fa con la stessa limpidezza di dettaglio e gusto del disegno. Nessuna immagine pubblicata da Choisy può essere paragonata, in termini di seduzione visiva, a quelle di Willis qui considerate. Questo diverso approccio, ma non solo questo, rivela una diversa sensibilità investigativa dei due padri della *construction history*, una diversità che, se indagata con cura, avrebbe probabilmente molto da insegnare sulla definizione stessa di *construction history*, sui suoi metodi d'indagine, sui suoi *aficionados*.

Il fatto che Choisy non abbia rigorosamente seguito la via tracciata da Willis deve essere messo a confronto con un altro particolare che lascia sorpresi: neppure Willis stesso ha poi approfondito quella strada e le tavole pubblicate nel 1842 non hanno avuto un seguito di pari livello, nonostante la nutrita serie di studi d'architettura da lui curata nei decenni successivi. Quell'exploit restò isolato, come se persino il suo autore fosse inconsapevole dell'impatto rivoluzionario provocato da quelle rappresentazioni.

L'*altra* bellezza

I disegni di Willis possono aiutare a riconsiderare la celebre distinzione formulata da Nikolaus Pevsner nell'Introduzione al volume *An Outline of European Architecture* (1942), tenendo presente che per Pevsner Willis "was not only the greatest observer; he was also an indefatigable collector of data, both visual and literary" (Pevsner 1972, 59): "A bicycle shed is a building; Lincoln Cathedral is a piece of architecture. Nearly everything that encloses space on a scale sufficient for a human being to move in, is a building; the term architecture applies only to buildings designed with a view to aesthetic appeal." (Pevsner 1942, 10)

Se proviamo ad applicare questa distinzione all'estradosso delle volte disegnate da Willis ci accorgiamo che qualcosa nell'affermazione di Pevsner non convince. La cattedrale di Lincoln è un "piece of architecture" e ovviamente è stata "designed with a view to aesthetic appeal": difficilmente potrebbe dirsi lo stesso dello spazio sopra le volte raffigurato da Willis, di quell'area dove si accede a fatica, usualmente *off limits*. Quei disegni rivelano un nuovo tipo di bellezza, che non può essere ridotto a quello usuale al quale fa riferimento Pevsner rinviando a scontate *aesthetic sensations* (Pevsner 1942, 10), ma neppure può essere ridotto al fascino della *machine* che Le Corbusier descrive più volte in *Vers une architecture*. La mancata corrispondenza con la definizione *architettonica* data da Pevsner non deve tuttavia portare necessariamente ad una svalutazione del fascino segreto di quelle volte, considerate in tutti i loro aspetti, anche in quelli che nelle intenzioni degli artefici non erano messi in mostra. Quale definizione della bellezza architettonica potrà infatti negare l'emozione suscitata da quelle forme che, pur celate alla vista dello spettatore, fanno parte integrante dell'edificio?

Le tavole di Willis portano alla ribalta questi dilemmi e costringono a ripensare il nostro rapporto con canoni estetici dati per scontati. Dopo aver visitato la cattedrale di Petersborough o aver percorso gli spazi coperti dalle *fan vaults* della cappella di Enrico VII, il visitatore ammira la bellezza di quelle costruzioni e rimane colpito dalla preziosità della cesellatura costruttiva che è stata ideata e realizzata proprio per stupire ed essere ammirata. Ma quando lo stesso spettatore vede le immagini di Willis che descrivono l'estradosso di quelle volte può essere tentato di affermare che forse quello che usualmente non si vede è altrettanto bello di quello che con tanta baldanza viene mostrato a tutti. Le forme sinuose di quegli imbuti di pietra costituiscono uno spazio che suscita forti emozioni: l'appassionato di architettura può associare quelle forme alle immagini del progetto *Intrapolis* di Walter Jonas o ad alcune tensostrutture progettate da Frei Otto. A quel punto, tuttavia, se davvero l'osservatore resterà ammaliato dalla costruzione *altra*, dal negativo di quello che i libri di storia dell'architettura hanno sempre proposto come capolavori di pietra, allora si sentirà imbarazzato, per-

ché dovrà forse ammettere, tra sé e sé, che egli addirittura preferisce il negativo al positivo, il nascosto al plateale, la pura essenzialità del connubio forma-funzione al ghirigoro un po' manieristico che può persino risultare stucchevole e che ha prodotto repliche di pessimo gusto.

Quell'imbarazzo è in realtà ingiustificato, anche se molta parte della storiografia corrente non aiuterebbe a comprendere il perché di quell'inusuale attrazione. Pevsner aveva buone ragioni per distinguere *architecture* e *building*, ma occorre chiedersi se, allora come oggi, quella concezione estetica non abbia finito per ridursi a pura tautologia: se l'architettura è quella che Pevsner e tanti suoi seguaci ci presentano come tale, allora certamente l'estradosso delle volte di Willis non può essere paragonato al suo ricamato intradosso. Se, tuttavia, l'architettura è anche, se non soprattutto, *res aedificatoria*, *ars aedificandi*, arte del costruire, allora il negativo della volta non è meno importante del positivo, il dettaglio fatto per piacere e per stupire non più originale e degno di ammirazione del particolare costruttivo che lo accompagna e lo sostiene.

La lettura delle tavole di Willis potrebbe anche fermarsi a questo livello di analisi, rivalutando un'interpretazione della fabbrica architettonica che tiene conto degli elementi e del tutto, senza mai imporre ostracismi che impediscono di comprendere la costruzione nel suo complesso. Ma quella lettura potrebbe anche spingersi oltre, proponendo all'attenzione degli studiosi non soltanto l'*altra faccia* di elementi costruttivi esaltati dalla critica corrente, ma anche costruzioni che possono essere associate al *bicycle shed* e che con la loro semplicità sanno suscitare *aesthetic sensations* paragonabili a quelle provocate da una visita alla cattedrale di Lincoln. Per approfondire questo punto si potrebbe ripartire dalle parole con le quali lo stesso Pevsner chiude l'Introduzione appena citata, dopo aver proposto un confronto 'esistenziale' tra architettura e arti affini (scultura e pittura): "An age without easel-pictures can be conceived without any difficulty, and, thinking of the predominance of easel-pictures in the 19th century, might well be regarded as a consummation devoutly to be wished. An age without architecture is impossible as long as human beings populate this world" (Pevsner 1942, 11). È una riflessione sul primato della *costruzione*, piuttosto che dell'*architettura*, attraverso la quale si allargano i confini di quanto Pevsner aveva illustrato poche righe prima. Una riflessione che probabilmente risente del clima bellico nel quale l'opera di Pevsner aveva preso forma: tra Liverpool e Londra, sotto la continua minaccia degli attacchi tedeschi, quando l'importanza di un solido riparo antiaereo diventava questione di vita o di morte. Lo sembra indicare la dedica che Pevsner scrisse per il suo libro in quel drammatico 1942: "This little book I dedicate to you, my three children, in East, North and West, hoping that, when you are grown up, the world will once again be safe for studying and enjoying the achievements of all nations" (Pevsner 1942). L'impossibilità di concepire una re-

altà senza architettura non può essere riferita alle definizioni estetiche che Pevsner aveva ricordato nella stessa Introduzione: qui è messa in primo piano l'essenzialità della *costruzione architettonica*, che non può essere disgiunta dall'essenza della vita umana, dalla necessità del riparo e dell'accoglienza.

Su questa via le tavole di Willis mettono in discussione i tradizionali confini tra *history of architecture*, *architectural history*, *construction history*. Leggendo gli scritti di coloro che si sono occupati delle molteplici *histories*, spesso e volentieri fra loro ideologicamente contrapposte, si assiste ad una danza di aggettivi e sostantivi ben descritta da Alexandrina Buchanan nel volume monografico dedicato a Willis (Buchanan 2013). Gli storici amano perdersi in simili distinzioni, contrapporre scuole di pensiero, redarre classifiche in-out, ma in ultima istanza la maggior parte di loro e di noi resta confusa di fronte all'interrogativo di fondo sull'atto costruttivo e sul modo di interpretarlo. Le immagini di Willis sono una provocazione per gli storici dell'architettura, dell'ingegneria, della costruzione e potrebbero essere prese a riferimento nel dirimere molte dispute identitarie. Probabilmente Willis si sarebbe trovato d'accordo con la distinzione di Pevsner tra *Lincoln Cathedral* e *bicycle shed*, ma i suoi disegni mostrano una passione per il dettaglio costruttivo e per l'ingegno in esso murato che sollecita a considerare l'architettura anche da un altro punto di vista, più vasto e più profondo di quello al quale tanta storiografia –spesso melensa, talvolta semplicemente ottusa— ci ha abituato. La possibilità che un ricovero per biciclette dia *aesthetic sensation*s paragonabili a quelle sollecitate da una cattedrale gotica non può essere esclusa a priori, anche se il valore storico dell'una e dell'altra non sono confrontabili. Nel groviglio epistemologico che allaccia *history of architecture*, *architectural history*, *construction history* dovrebbe esserci spazio per esaminare con rigore questa eventualità.

Il primato della *geometrical faculty*

L'attenzione che Willis rivolge all'efficacia dimostrativa e didattica della geometria e del disegno, della quale le tavole sino a qui considerate sono l'espressione più originale e feconda, ha un naturale corrispettivo negli scritti della maturità dedicati alla meccanica. Il suo approccio alla disciplina è di tipo cinematico, proprio perché attraverso di esso è possibile costruire una perfetta corrispondenza tra meccanica e geometria, sino ad operare una sorta di riduzione della prima alla seconda. In *Principles of mechanism* (Willis 1841) si presenta una teoria che ha lo scopo di circoscrivere e analizzare il *pure mechanism*: "I have confined myself to the Elements of Pure Mechanism, that is, to those contrivances by which motion is communicated purely by the connexion of parts, without requiring the essential intermixture of dynamical effects" (Willis 1841, xii-xiii). Lo studio del

movimento delle singole parti è nettamente separato dalle "considerations of forces, with which it has been usually mixed up" (Willis 1841, xviii). La cinematica diventa nelle mani di Willis, seguendo la tradizione francese inaugurata da André-Marie Ampère ed esplicitamente ricordata nei *Principles of mechanism* (Willis 1841, viii), uno strumento ideale per analizzare i movimenti delle macchine facendo uso della sola geometria elementare, nello spirito del programma culturale che l'amico Whewell aveva ribadito a più riprese nei suoi scritti sugli obiettivi e i modi dell'educazione liberale.

L'approccio geometrico, favorito da Whewell e Willis nei confronti di quello analitico, trovava nel testo di Willis una dimostrazione esemplare. Nel suo saggio *Of a liberal education in general; and with particular reference to the leading studies of the University of Cambridge* Whewell precisava che "Such branches of mathematical science are often called *Analytical*, and *Analysis* is often opposed to Geometry. This opposition is not very exact; for Geometry has also its Analysis" (Whewell 1850, 39). Detto questo, tuttavia, la requisitoria contro le *analytical calculations* non lasciava spazio ad ambiguità interpretative:

> In the one case, that of geometrical reasoning, we tread the ground ourselves, at every step feeling ourselves firm, and directing our steps to the end aimed at. In the other case, that of analytical calculation, we are carried along as in a rail-road carriage, entering it at one station, and coming out of it at another, without having any choice in our progress in the intermediate space. (Whewell 1850, 41)

Una bella immagine figlia del suo tempo, che permetteva a Whewell di proseguire la corsa affermando che: "It is plain that the latter is not a mode of exercising our own locomotive powers; and in the same manner analytical processes are not a mode of exercising our reasoning powers" (Whewell 1850, ibidem). Considerazioni analoghe costellano tutta la quinta sezione del suo *Liberal education in general*, intitolata *Of Analytical Mathematics as an Educational Study*, sempre per ribadire che "mere analytical processes are no proper discipline of the reason, on account of the difference of form between such reasoning and the reasoning with which men are mainly and commonly concerned" (Whewell 1850, 43).

Willis desiderava ricondurre la costruzione delle macchine alla chiarezza della matematica e i suoi *Principles of mechanism* rinunciavano all'uso del calcolo differenziale e integrale (salvo un'eccezione, sulla quale torneremo): "there appears no reason why the construction of a machine for a given purpose should not, like any usual problem, be so reduced to the dominion of the mathematician, as to enable him to obtain, by direct and certain methods, all the forms and arrangements that are applicable to the desired purpose, from which he may select

at pleasure" (Willis 1841, iii-iv). Nello stesso tempo egli aveva ben presenti gli obiettivi descritti da Whewell e quelli che perseguiva la *Society for the Diffusion of Useful Knowledge*. Willis avrebbe inoltre sottoscritto gli intenti dichiarati da Henry Moseley nelle prime righe della prefazione al *Treatise on Mechanics applied to the Arts; including Statics and Hydrostatics*: "The following work contains treatises on the sciences of Statics and Hydrostatics, comprising the whole theory of EQUILIBRIUM. It was intended as the first volume of a *course* of Natural Philosophy, for the use of those who have no knowledge of Mathematics, or who have made but little progress in their mathematical reading" (Moseley 1839, 9; idem in Moseley 1834). Vent'anni più tardi Rankine ribadirà gli stessi concetti nella *Preliminary Dissertation* già citata, tornando ancora una volta sul ruolo che la matematica deve avere nella formazione scientifica degli ingegneri: "In the first place it will be universally admitted, that as far as is possible, mathematical intricacy ought to be avoided" (Rankine 1858, 9). Invocando l'importanza della *simplicity* e portando a supporto della sua tesi il parere del matematico e astronomo John Herschel, Rankine affermava poco oltre che: "In treating of the practical application of scientific principles, an algebraical formula should only be employed when its shortness and simplicity are such as to render it a clearer expression of a proposition or rule than common language would be, and when there is no difficulty in keeping the thing represented by each symbol constantly before the mind" (Rankine 1858, 10).

Questa grande attenzione riservata a coloro che "have no knowledge of Mathematics, or who have made but little progress in their mathematical reading" era una caratteristica della letteratura tecnica britannica nel corso dell'Ottocento, alla quale deve essere associata, ad un livello superiore di formazione tecnico-scientifica, la distinzione tra *permanent education* e *progressive education*, dove l'analisi matematica più sofisticata e astratta era riservata alla seconda ma fortemente sconsigliata per la prima. Gli ingegneri dediti alle costruzioni si fermavano di solito al livello della *permanent education* e gli effetti cominciavano ad essere evidenti, in particolare rispetto ai risultati ottenuti dalla scuola francese.

È chiaro che Willis scrisse i suoi *Principles of mechanism* avendo sempre presente lo spirito didattico descritto da Moseley, Whewell, Rankine e da tanti altri colleghi suoi contemporanei, sullo sfondo di una polemica neppure troppo velata con le nuove tendenze di matematica e meccanica analitica in voga sul Continente. Anche se non alla portata di chi non avesse mai studiato matematica, la lettura dei *Principles of mechanism* richiedeva una conoscenza elementare della materia, che non andava al di là dei più semplici rudimenti. La scelta di limitare il campo d'indagine alla cinematica aiutava a ridurre l'apparato matematico all'essenziale. Risulta curioso e divertente, a questo proposito, il tentativo di Alfred Bartholomew di trascinare Willis nelle sue imprese definendolo *Professor of*

Architectural Dynamics (Buchanan 2013, 110), appellativo che non poteva essere più distante dalle aspirazioni e dai programmi culturali che caratterizzavano il suo operato.

Per associare il nome di Willis a qualche forma d'indagine *dinamica* e di matematica superiore occorreva attendere quel punto di non ritorno —per Willis e per l'ingegneria, non soltanto inglese— rappresentato dall'incidente del *Dee bridge* (1847), dove cinque persone persero la vita (Lewis e Gagg 2004). Willis fu allora chiamato a far parte della *Royal Commission* che doveva occuparsi dei problemi connessi all'uso delle strutture metalliche nelle costruzione ferroviarie, dove il tema era eminentemente dinamico, non certo esclusivamente cinematico. In quell'occasione fu costretto ad occuparsi di aspetti che in gran parte esulavano dalle sue competenze ma che erano ritenuti adeguati alla sua preparazione.

Quello che si legge nella sua relazione conclusiva, pubblicata come *Appendix B* del *Report of the Commissioners Appointed to Inquire into the Application of Iron to Railways Structures* (Report 1849) lascia pochi dubbi sull'imbarazzo che Willis deve aver provato di fronte al compito assegnato. Le prove di carico si rivelano difficili e ad un certo si verificano alcuni incidenti:

> But whenever either bar broke, the car having lost its support, rolled head-over-heels into the yard, and usually some hours were consumed in repairing the consequent mischief; also, the fear of such accidents made it necessary for the observers to escape to a safe distance before the car was released, instead of closely watching the phenomena of its passage. (Report 1849, 182)

Oltre ai problemi tecnici legati ai dispositivi usati per le indagini sperimentali, portate avanti con ammirevole impegno in tempi molto stretti (dei quali Willis si lamenta giustamente a più riprese), ai commissari si presentano ben presto difficoltà apparentemente insormontabili legate all'apparato matematico da associare alle prove sperimentali. È subito chiaro, innanzitutto allo stesso Willis, che la sua preparazione è del tutto inadeguata alla sfida che quei problemi ponevano. Per questa ragione è richiesto l'intervento di George Gabriel Stokes, già allievo di Willis e destinato a diventare uno dei più brillanti fisico-matematici dell'epoca. Anche Stokes, tuttavia, si trova in difficoltà, come testimonia il suo articolo *Discussion of a Differential Equation relating to the Breaking of Railway Bridges* (Stokes 1849), da leggere in parallelo con l'*Appendix B*. Stokes, che nel 1849 diventa *Lucasian Professor of Mathematics* a Cambridge, lavora con impegno sull'equazione proposta da Willis, ma stenta ad ottenere risultati e a trovare una buona intesa tra modello matematico e dati ricavati dalle prove sperimentali. La conclusione della sua lunga memoria dà un'idea precisa delle incertezze che avevano condizionato l'indagine:

> In conclusion, it will be proper to state that this 'Addition' has been written on two or three different occasions, as the reader will probably have perceived. It was not until a few days after the reading of the paper itself that I perceived that the equation (16) was integrable in finite terms, and consequently that the variables were separable in (4) (…). The fact of the integrability of equation (4) in the form given in art. 7, to which I had myself led from the circumstances above mentioned, has since been communicated to me by Mr. Cooper, Fellow of St John's College, through Mr. Adams, and by Professors Malmsten and A. F. Svanberg of Upsala through Professor Thomson; and I take the opportunity of thanking these mathematicians for the communication. (Stokes 1849, 734–735)

Le difficoltà erano notevoli e risiedevano nella spinosità del problema dinamico. La necessità di far intervenire da Upsala due analisti del calibro di Carl Johan Malmsten e Adolf Fredrik Svanberg fa intuire in quali sfere si muoveva la trattazione del problema matematico. Ma anche dal punto di vista strettamente meccanico gli interrogativi non ammettevano risposte scontate. Come già aveva notato Homersham Cox in un articolo pubblicato sul *The Civil Engineer and Architect's Journal* nel Settembre 1848, quindi prima dell'uscita del *Report* della *Royal Commission*, le interpretazioni del disastro del *Dee bridge* erano così confuse da rendere plausibili due ipotesi opposte, una delle quali assai bizzarra: "There seems to exist great discrepancy of opinion as to the effect of the velocity of transit. Some have imagined that it may become a source of safety, by causing the railway train to pass over before the girder has had time to yield. Others, again, have estimated the effect of the moving load as highly as six or seven times that of the same load at rest" (Cox 1848, 259).

Il fatto che la scienza dei carichi dinamici fosse allora agli esordi e grazie allo sviluppo delle ferrovie fosse destinata a diventare una delle più interessanti nel campo dell'ingegneria strutturale, non toglie l'impressione che anche per calcoli molto meno impegnativi Willis si trovasse in difficoltà. È la sensazione che si prova leggendo per intero l'*Appendix B*, in particolare nel passaggio dove si descrive la deformazione della trave sotto carico e si rinvia alle formule descritte da Louis Navier nel *Résumé des Leçons* (Navier 1833), dando la netta impressione di essere in cerca di formule *prêt-à-porter*, piuttosto che di una teoria da applicare al caso esaminato. Questa parte precede la sezione intitolata *Theoretical Investigation of the Trajectory*, nella quale Willis introduce l'intervento di Stokes con queste parole: "Having proceeded thus far, however, I found the discussion of this equation involved in so much difficulty, that I was compelled to request my friend G. G. Stokes, Esq., Fellow of Pembroke College, to undertake the development of it" (Report 1849, 198).

La stessa sensazione d'incertezza di fronte alle applicazioni del calcolo differenziale e integrale emerge in una richiesta che Willis presenta a Stokes cinque

giorni prima della chiusura del *Report* (firmato dai commissari il 26 Luglio 1849). In una lettera datata "Parker's Place, July 21, 1849" egli chiede al giovane collega di rivedere un grafico alla luce dei nuovi dati sperimentali oppure, "if you are too tired of the subject to undertake this, which I fear is the case", di mostrare a lui "the short way to do it" (Stokes 1907, 125). Leggendo questi ed altri passi si notano le titubanze in alcuni punti cruciali della trattazione matematica. Assume allora un tono ambiguo quanto Willis scrive in riferimento alla comprensione del procedimento adottato: "The mathematical methods employed for this purpose are, from their nature, probably unintelligible to the majority of practical men, for whom the present essay was written (…)" (Report 1849, 198). Qui come altrove risulta chiaro che l'imbarazzo di fronte a quei calcoli era, in primo luogo, dello stesso Willis e che la formula "unintelligible to the majority of practical men" era frutto di pura retorica, usata ad arte per evitare espressioni più precise, che avrebbero inevitabilmente coinvolto Willis stesso e le sue competenze *scientifiche*.

Un altro indizio che permette di valutare la preparazione di Willis rispetto a problemi che non potevano essere trattati con strumenti matematici elementari si trova nella prima edizione dei *Principles of mechanism* (1841), nella parte dedicata alla *Communication of motion by rolling contact*. Nell'unico passaggio di tutta l'opera nel quale si propone l'uso del calcolo integrale per analizzare le proprietà delle *rolling curves*, Willis rimanda prima ai contributi di Eulero e, in seconda battuta, ad un lavoro del Rev. Hamnett Holditch, intitolato *On Rolling Curves* e pubblicato nei *Transactions of the Cambridge Philosophical Society* (Holditch 1842; letto il 10 Dicembre 1838). Oltre a non entrare personalmente nell'argomento, Willis si affida a Holditch anche per un procedimento semplificato: "I have substituted in the next article a simpler but more limited investigation, for which I am indebted to the author of the paper in question" (Willis 1841, 242).

In un altro caso, questa volta relativo ad un'elaborata trattazione geometrica, Willis non chiede aiuto, ma finisce per guadagnarsi una severa critica da parte di Jean-Baptiste Bélanger. Quest'ultimo aveva elogiato l'autore dei *Principles of mechanism*, ma in due occasioni aveva anche messo in evidenza errori a proposito degli iperboloidi di rivoluzione descritti da Willis nella sezione *Communication of motion by rolling contact* appena menzionata (Willis 1841, 31 e ssgg.). La critica si trova espressa una prima volta nel *Résumé d'une théorie de l'engrenage hyperboloïde*, pubblicato nei *Comptes rendus de l'Académie des Sciences* (Bélanger 1861) e successivamente nel *Traité de cinématique*, pubblicato tre anni dopo (Bélanger 1864). Willis riporta le osservazioni del collega nella seconda edizione dei *Principles of mechanism* (Willis 1870), dove viene trascritto alla lettera quanto Bélanger aveva affermato nella monografia del 1864 (Bélanger 1864,

145): “M. Willis —faute d’une étude suffisamment approfondie de la question— a inexactement indiqué la détermination de ces deux surfaces, en supposant, comme d’autres auteurs l’ont admis après lui, que la génératrice de contact doit partager la plus courte distance des deux axes en deux parties réciproques aux vitesses angulaires” (Willis 1870, 33, nota*). L’apparente correttezza di Willis nell’ammettere l’errore gli fa onore, ma fa anche capire che persino sulle questioni geometriche le lacune c’erano e la scuola francese aveva ancora molto da insegnare. Willis, inoltre, omette di citare il passaggio originale della memoria di Bélanger pubblicata nei *Comptes rendus*, pur lasciando intendere di riferirsi a quel testo (“In this memoir…”, cfr. Willis 1870, 32, nota*). Nel *Résumé* Bélanger afferma che:

> Mais, faute d’une étude suffisamment réfléchie de la matière, il lui est échappé deux graves erreurs: l’une d’admettre que deux hyperboloïdes de révolution ayant une génératrice commune sont, par cela seul, tangents suivant cette ligne; l’autre de supposer que la génératrice de contact doit partager la plus courte distance des deux axes en deux parties réciproques aux vitesses angulaires, tandis que, lorsque les axes sont à angle droit, ces deux parties qui sont les rayons des cercles de gorge des deux hyperboloïdes, doivent être réciproques aux carrés des vitesses angulaires. (Bélanger 1861, 127)

È evidente che Willis ha voluto presentare ai suoi lettori la versione meno severa della critica mossagli dal collega francese. Probabilmente avrebbe reagito con ugual eleganza, ma forse con altrettanta velata reticenza, se nel caso di quell’esercizio di stile che è costituito dal saggio *An Architectural History of the Church of the Holy Sepulchre* (1849; come è noto Willis non si era mai recato a Gerusalemme), qualcuno gli avesse fatto notare che un “pointed arch” è un arco a sesto acuto, non un “arco ottuso”, come lui scrive facendo riferimento all’opera di Bernardino Amico (Willis 1849, 163; Amico 1620, 44). Una svista di poco conto, che getta tuttavia un’ombra sulla cura filologica di Willis, di solito considerata esemplare.

Nei *Principles* Willis ribadisce la necessità di rivolgersi ai *practical men*, usando un linguaggio che sia a loro comprensibile e che non li escluda da quella letteratura meccanica che doveva essere considerata indispensabile bagaglio teorico del tecnico che si dedicava al progetto di nuove macchine e costruzioni. La sua posizione, tuttavia, non può ridursi a quella del teorico consapevole dell’indispensabile dialogo tra teoria e prassi, tra la speculazione geometrico-meccanica e l’ingegnosità caratteristica dei migliori *practical men*, così come Rankine sostiene con forza nella *Preliminary Dissertation*. L’impressione generale che si ha, leggendo i *Principles* e l’*Appendix B*, è che Willis utilizzasse strumenti algebrici e geometrici elementari perché non sarebbe stato in grado di uti-

lizzarne altri più sofisticati. Con quegli strumenti, tuttavia, nessun ingegnere di metà Ottocento sarebbe stato in grado di andare lontano, nel caso in cui si fosse dovuto occupare di strutture metalliche, di resistenza dei materiali, di teoria dell'elasticità seguendo le indicazioni della migliore trattatistica dell'epoca.

Per quanto riguarda il confronto con la scuola francese, sono ben noti i limiti di alcuni studi portati avanti da celebri elasticisti, sui quali William Thomson, James Clerk Maxwell e altri fisici britannici si soffermarono più volte, anche per ridicolizzarne l'approccio molecolare (Wise e Smith 1989). Alle critiche prettamente scientifiche si possono aggiungere quelle di carattere tecnico, ben sintetizzate dall'osservazione del fisico e ingegnere svizzero Jean-Daniel Colladon, messa in rilievo da Ivor Grattan-Guinness (Grattan-Guinness 1984, 33):

> Le bateau fini, il donna des résultats remarquables; il marcha plus vite qu'auparavant, en dépensant moins de la moitié de combustible. Je conduisis ce bateau sur la rivière la Seine au quai Voltaire et je lançai une circulaire à des membres de l'Institut pour les inviter à venir le visiter. J'écrivis à MM. Poncelet, Navier, Dupin, Delau [sic], etc.; et je fus étonné de voir comme ils connaissaient peu la construction des machines. Je fus obligé de leur faire la démonstration de toutes les pièces. (Colladon 1893, 211)

La correttezza di questi rilievi, che sottolineano certe idiosincrasie della scuola francese, non può far dimenticare la grande rilevanza dei suoi contributi scientifici: a partire dagli anni Venti del XIX secolo gli studiosi formatisi all'*École polytechnique* misero a punto un apparato scientifico al quale, in parte, si riferiscono ancora oggi i corsi di base di scienza delle costruzioni per ingegneri e architetti. Il divario tra le conoscenze raccolte in quei contributi e quanto Willis potè offrire come sua personale competenza nel ruolo di *Jacksonian Professor of Natural Philosophy* coinvolto nella *Royal Commission* appare, comunque lo si voglia interpretare, molto ampio.

Le riflessioni elaborate da Willis a margine della *Great Exhibition* del 1851 fanno pensare che quel ritardo e il relativo problema di formazione degli ingegneri britannici gli fossero ben presenti e avessero suscitato in lui serie preoccupazioni, da associare alle indagini delle *Parliamentary Commissions* che negli anni Cinquanta dell'Ottocento furono incaricate di studiare le riforme da adottare nell'Università di Cambridge. Nella *Lecture* dedicata ai risultati della *Great Exhibition* egli metteva in guardia da un pericolo di cui si parlava ormai da qualche decennio e che ancora a metà del secolo rappresentava una spina nel fianco dell'ingegneria britannica: "unless we also begin to apply science to this subject, we run considerable risk of falling behind our ingenious neighbours" (Willis 1852, 315). Poco prima Willis aveva osservato "how much good service is rendered by the superior mathematical and theoretical education of French engi-

neers" (Willis 1852, ibidem). Non si può escludere che fossero anche le difficoltà patite sulla propria pelle nel corso dei lavori della *Royal Commission* a spingere Willis a lanciare quel grido d'allarme, così lucido e, nel contempo, così poco 'patriottico'. Se era vero, come affermava Willis nella *Lecture*, che alcuni libri di meccanica "are necessarily rather intended to teach machinery to mathematicians, than to teach mathematics to mechanists" (Willis 1852, 304), non si poteva negare che "at least in one branch of mechanics, the 'strength of materials', the value of theoretical and experimental science has been fully recognised by practical engineers, and the Britannia bridge may be quoted as a triumphant example of the advantages that arise when theory and practice go hand in hand" (Willis 1852, ibidem). Il *Britannia bridge* (1850) serviva ad esorcizzare il brutto ricordo del *Dee bridge* (1846).

Nel campo della meccanica strutturale Willis non ebbe tempo di assistere al compimento di quella svolta verso il calcolo grafico delle strutture che si verificò nel corso della seconda metà dell'Ottocento. Con la moderna *statica grafica* la geometria di immediato impatto visivo diventava il doppio perfetto dell'analisi meccanica e lo spirito geometrico riprendeva per alcuni anni un posto di rilievo nel campo dell'ingegneria, offrendo un'allettante alternativa alle soluzioni 'analitiche' dei problemi di meccanica strutturale. Willis e Whewell avrebbero assistito con favore e soddisfazione a quest'ulteriore affermazione della *geometrical faculty*.

Bibliografia

Amico, Bernardino. 1620. *Trattato delle Piante & Immagini de Sacri Edifizi di Terra Santa Disegnate in Ierusalemme secondo le regole della Prospettiva, & vera misura della lor grandezza*. Firenze: P. Cecconcelli.

Bélanger, Jean-Baptiste. 1861. Résumé d'une théorie de l'engrenage hyperboloïde. *Comptes rendus hebdomadaires des séances de l'Académie des Sciences*, 52: 126–130.

Bélanger, Jean-Baptiste. 1864. *Traité de cinématique*. Paris: Dunod et Gauthier-Villars.

Beltrami, Luca. 1898. *Il Pantheon. La struttura organica della cupola e del sottostante tamburo. Le fondazioni della Rotonda, dell'avancorpo e del Portico. Avanzi degli edifici anteriori alle costruzioni adrianee. Relazione delle indagini eseguite dal R. Ministero della Pubblica Istruzione negli anni 1892–93 coi rilievi e disegni dell'Architetto Pier Olinto Armanini*. Milano: Tipografia Umberto Allegretti.

Buchanan, Alexandrina. 2013. *Robert Willis and the Foundation of Architectural History*. Woodbridge: Boydell Press.

Choisy, Auguste. 1904. Choisy's reply (Royal Gold Medal). *Journal of the Royal Institute of British Architects*, XI, 3d series: 451–453.

Clark, John Willis. 1900. Robert Willis. In *Dictionary of National Biography,* edited by Sidney Lee, LXII: 21–23. New York: Macmillan Company; London: Smith, Elder, & Co.

Colladon, Jean-Daniel. 1893. *Souvenirs et Mémoires*. Genève: Aubert-Schuchardt.

Cox, Homersham. 1848. The Dynamical Deflection and Strain of Railway Girders. *The Civil Engineer and Architect's Journal*, Sept. 1848: 258–264.

Farish, William. 1822. On Isometrical Perspective. *Transactions of the Cambridge Philosophical Society*, 1, 1: 1–19.

Grattan-Guinness, Ivor. 1984. Work for the Workers: Advances in Engineering Mechanics and Instruction in France, 1800–1830. *Annals of Science*, 41: 1–33.

Holditch, Hamnett. 1842. On Rolling Curves. *Transactions of the Cambridge Philosophical Society*, 7: 61–82.

La Hire, Philippe. 2013. *Philippe de La Hire (1640–1718). Entre architecture et sciences*, sous la direction d'Antonio Becchi, Hélène Rousteau-Chambon et Joël Sakarovitch. Paris: Picard, 2013.

Le Corbusier-Saugnier. 1923. *Vers une architecture*. Paris: Les Editions G. Crès et C.ie

Lewis, Peter R. e Colin R. Gagg. 2004. Aesthetics Versus Function: The Fall of the Dee Bridge, 1847. *Interdisciplinary Science Reviews*, 29, 2: 177–191.

Marsden, Ben. 2004. 'The progeny of these two "Fellows"': Robert Willis, William Whewell and the science of mechanism, mechanics and machinery in early Victorian Britain. *British Journal for the History of Science*, 37, 4: 401–434.

Martines, Giangiacomo. 2015. The Conception and Construction of Drum and Dome. In *The Pantheon. From Antiquity to the Present*, edited by Tod A. Marder and Mark Wilson Jones, 99–131. Cambridge: Cambridge University Press.

Minutes. 1875. *Minutes of Proceedings of the Institution of Civil Engineers; with Other Selected Papers*, XLI, Session 1874–75, Part III, edited by James Forrest, 206–210 (necrologio di Robert Willis). London: Institution of Civil Engineers.

Moseley, Henry. 1834. *A Treatise on Mechanics applied tot he Arts; including Statics and Hydrostatics*. London: John W. Parker.

Moseley, Henry. 1839. *A Treatise on Mechanics applied to the Arts; including Statics and Hydrostatics*. Second edition, improved. London: John W. Parker.

Navier, Louis. 1833. *Résumé des Leçons données à l'École des Ponts et Chaussées sur l'Application de la Mécanique à l'Établissement des Constructions et des Machines*. Première Partie, Deuxième édition corrigée et augmentée. Paris: Chez Carillan-Goeury.

Pevsner, Nikolaus. 1942. *An Outline of European Architecture*. Harmondsworth, UK; New York, USA: Penguin Books.

Pevsner, Nikolaus. 1972. Willis. In Nikolaus Pevsner, *Some Architectural Writers of the Nineteenth Century*, 52–61. Oxford: Clarendon Press.

Piranesi, Francesco. 1790. *Raccolta de' Tempj antichi*. Parte II. Roma: presso l'autore.

Rankine, William John Macquorn. 1858. *A Manual of Applied Mechanics*. London and Glasgow: Richard Griffin and Co.

Report. 1849. *Report of the Commissioners Appointed to Inquire into the Application of Iron to Railway Structures. Presented to both Houses of Parliament by Command of Her Majesty*. London: W. Clowes and Sons.

Schübler, Johann Jacob. 1732. *Synopsis Architecturae Civilis Eclecticae* (…). Nürnberg: In Verlag Johann Christoph Weigels Seel. Wittwe.

Stokes, George Gabriel. 1849. Discussion of a Differential Equation relating to the breaking of Railway Bridges. *Transactions of the Cambridge Philosophical Society*, 8: 707–735.

Whewell, William. 1841. *The Mechanics of Engineering intended for the use in Universities and in Colleges of Engineers*. Cambridge: University Press.

Whewell, William. 1850. *Of liberal education in general; and with particular reference to the leading studies of the University of Cambridge*. Part I, Principles and recent history, second edition. London: John W. Parker.

Willis, Robert. 1821. *An Attempt to Analyse the Automaton Chess Player*. London: J. Booth.

Willis, Robert. 1833. On the Mechanism of the Larynx. *Transactions of the Cambridge Philosophical Society,* 4: 323-352.

Willis, Robert. 1838. On the Teeth of Wheels. *Transactions of the Institute of Civil Engineers*, 2: 89–113.

Willis, Robert. 1841. *Principles of Mechanism, Designed for the Use of Students in the Universities, and for Engineering Students Generally*. London: John W. Parker.

Willis, Robert. 1842. On the Construction of the Vaults of the Middle Ages. *Transactions of the Royal Institute of the British Architects*, 1, 2: 1–69.

Willis, Robert. 1849. An architectural history of the church of the Holy Sepulchre. In George Williams, *Holy City. Historical, topographical, and antiquarian notices of Jerusalem,* second edition, II: 129–600. London: John W. Parker; Cambridge: J. Deighton.

Willis, Robert. 1852. Machines and Tools for Working in Metal, Wood, and Other Materials. In *Lectures on the Results of the Great Exhibition of 1851*, 293–319. London: David Bogue.

Willis, Robert. 1870. *Principles of Mechanism, Designed for the Use of Students in the Universities, and for Engineering Students Generally*, second edition. London: Longmans, Green, and Co.; New York: John Wiley & Son.

Willis, Robert. 1907. Letter to George Gabriel Stokes, Parker's Place, July 21, 1849. In *Memoir and Scientific Correspondence of the late Sir George Gabriel Stokes*, edited by Joseph Larmor, 1: 124–125. Cambridge: Cambridge University Press.

Willis, Robert. 1972–1973. *Architectural History of some English Cathedrals. A collection in two parts of papers delivered during the years 1842–1863*. Chicheley: Paul P.B. Minet.

Wise, Norton Matthew e Crosbie Smith. 1989. *Energy and Empire. A biographical study of Lord Kelvin*. Cambridge: Cambridge University Press.

Willis's "On Vaults of the Middle Ages": some notes about his heuristic approach, his drawing and Viollet-le-Duc's reception

Javier Girón

In June 1904 the great architectural and construction historian Auguste Choisy received from the RIBA the Royal Gold Medal. In his acceptance speech he recalled, from the distance of the years, an unforgettable scene of his childhood (Choisy 1904, 452):

> Presque enfant, feuilletant les livres de la bibliothèque de mon père, j'eus la bonne fortune de rencontrer la Mémoire du Reverend Robert Willis sur les voûtes du moyen âge. Ce fut une révélation. C'est ainsi, me dis-je, que les formes doivent être analysées, c'est ainsi que le dessin doit exprimer la structure. Et lorsque j'essayai de résumer les procédés romains, j'eus sans cesse présent comme un modèle de méthode ce mémoire sans précèdent, qui marque á la fois les débuts et le dernier terme de la critique architecturale.[1]

Obviously he was speaking about the article "On the Construction of the Vaults of the Middle Ages" that Robert Willis had published in 1842 (Willis, 1842). But, when one remarks how little this article has been studied until now, and at the same time how much it was appreciated as a milestone by an immense figure such as Choisy more than a century ago, there is something that doesn't fit. One has the impression that it has been unfairly overlooked.[2]

My purpose is to reconsider the article written by Willis. Choisy gives us a hint of what is worth studying: it praised his method as a "model without precedent" and admired how the drawings "explain the structure". Therefore we will focus on these two aspects and explore the relationships between them.

I will prove that the novelty of Willis' method lies in the heuristic hypotheses he introduced in order to study and analyze construction. I will show how they demanded correlated new forms of drawing to help materialize his ideas and to reach concrete results. We will see how some of them were borrowed and how some others were devised by Willis himself.[3]

Broadening our temporal panorama, we will also show that this pioneering work proved that it was possible to study Gothic construction relying on a convenient method. This will add to existing studies of Greek construction. Finally, we will review how Willis' work was received in France and the ambiguous fortune it experienced once immersed in the French version of the history of Gothic construction.

Willis's heuristic approach

Searching for Ancient construction. The need for a specific method for Gothic construction.

The publication in 1842 of Willis' work on Gothic vaults inaugurated the scholarly study on Gothic construction. But it was not the first work to show some interest in ancient construction. In addition to those more remote and controversial works on Roman construction by Piranesi, since the beginning of the century there existed a growing interest about the construction of Greek architecture, which rivaled with Gothic architecture in the battle of the styles.

A landmark of this new approach to Greek construction was Lord Elgin's expedition (c.1801–1802). Luciana Gallo (2009) has revealed both the quality of the drawings made by Lord Elgin's team and the originality of its emphasis on construction.

During his travels in Sicily, Samuel Angell and William Harris picked-up, here and there, details of construction from the ruins.[4] Other travellers observed even the material footprints of the ancient methods. Edward Dodwell, in his *A classical and topographical tour through Greece,* discovered and carefully reproduced the marks on the surface of a drum used to trace the fluting of a column —Willis would also eagerly search for these kinds of proofs for Gothic construction instead (Dodwell 1819, 585–586). Henry Inwood illustrations of the *Erechtheion* (Inwood, 1827, pl.14) dealt also with its construction, as did many of those prepared by John Peter Gandy for *Unedited Antiquities of Attica* (Society of Dilletanti 1817*)*. It is worth remembering specially the three-dimensional constructive details of the Temple of Agrigento by C. R. Cockerell for the *Supplement to the Antiquities of Athens* 1830. (Cockerell, Kinard, Donaldson et. al. 1830, pl. V, VIII). A book, *The Prolusiones Architectonicae* of William Wilkins summarized much of the knowledge already acquired in the 30's (Wilkins 1837).[5]

What can be said in short is that the first three decades saw the awakening of the interest on Greek construction, with had an eye on the contemporary practice, —as it will be the case for Willis's work on vaults. A telling instance of how this approach lasted is an article in *The Builder* (Scoles, 1846), which compared the construction of the Agrigento Temple and Nelson's Column.

This was the context, for anyone well informed —as Willis was, as he owned several books of this kind (Hodgson, 1874); by contrast, knowledge about Gothic construction appeared as a land still to be conquered.[6]

For anyone who wanted to embark on this research, the initial conditions were more difficult. The state of ruin of many buildings in Greece (the case of Agrigento, suddenly abandoned half completed) allowed close examination of separate elements such as foundation stones, drums of columns or fragments of entablatures. The researcher could afterwards, as if he was dealing with a puzzle, assign them their proper place and mission. To define and draw a constructive section of a temple was thus achievable.[7]

This was clearly not the case when studying a Gothic building. The researcher had to face an almost insurmountable obstacle: how could the inside of the building's mass be seen? How could their different components be separated and examined? This was just a preliminary question to be tackled, before approaching the main question of finding the rules and describe the historical changes of that particular building.[8]

Understandably, Willis' article provided with amazing and fascinating answers for his contemporaries. Not only because of the amount of fresh information he supplied in it, but because he managed to see virtually the inner construction; and he showed how to do it.

The key was, of course, putting into practice scientific habits (which was the natural approach for someone with his scientific background): to observe things first hand, to be rigorous while measuring and recording data, checking hypothetical guessing... While all of this was necessary, still it was not enough.

Willis' answer. The heuristic approach: how to see at a Gothic vault

Willis could achieve his goal thanks to his attachment to some uncommon heuristic procedures. The first one was that it is important to keep in mind that the apparent construction could not coincide with the real one. It was a principle he had already pointed out in his *Remarks on the Architecture of the Middle Ages,* and one of which he was particularly proud of having foud out. He considered the separation of decorative construction and real construction was a constant in the architecture of all time, and particularly in the Gothic period (Willis 1835, p. v.; 15–27).[9]

The second hypothesis is that Gothic architecture was governed by “rules” —as was the case in Vitruvian architecture— which may be discovered. The possibility of drawing an intelligible history depended on knowing those rules. It was an idea he had already stated several times in his *Remarks* referring to their decorative aspects (Willis 1835, 25). Now he had to prove that those rules played a significant role in the configuration of this crucial part of the Gothic buildings: the vault. He should find a set of “geometric rules” that matched the facts, and achieve to describe “the different steps by which they appear to have been led on from the simple cross-ribbed vault to the fan tracery” (Willis 1842, 13).[10]

Finally, Willis argued that change, the passage from one shape to another or from one set of rules to the next, is often caused by aesthetic reasons, a certain weariness of the usual solutions: “Whatever propriety of beauty a given form may possess, we find , by long continued use and multiplication, it palls upon the eye and requires change” (Willis 1842, 66).[11] This represents a heuristic approach clearly different from the positions taken by Viollet-le-Duc.[12]

A narrative of the evolution of Gothic vaults from Willis's heuristic approach

By putting together the different heuristic positions, Willis was able to “build” the “logic” of the evolution and the rules of the Gothic vaults in England.

In the English vaults, Willis noticed several features in which the difference between apparent and actual construction were very telling. One of them was a very common solution for the springing of the vault built in “tas-de-charge”.[13] While the actual construction until a certain point, almost half of its height, is kind of a corbel, made at the beginning of some overhanging horizontal rows of stone bonded into the wall, seen from the outside the arches seem to be truly working from the very beginning. (Willis 1842, 6–7).[14]

Another feature was the fan vault: looking to the soffit, it is apparently sustained by ribs. However the real working system is only revealed by standing on the back of the vault: “It thus appears that the rib and pannel construction was finally driven out and superseded by solid masonry, although to all appearance the vaults continued to be formed of ribs and pannels as usual” (Willis 1842, 42).

Willis not only detected those realities hidden from the view. He managed to find a common thread between them: a chain linking the initial vault of intermediate ribs with ligature vaults and fan vaults.

Willis believed that changes were due largely to the claim to give a “good shape” to the spandrel, seen as a “solid”. In lierne vaults the spandrel could take different forms with a strong aesthetic impact —derived from the different curvatures of the arches at the spring that could be “calculated” by a geometric procedure (Willis 1842, 13–25).

At some point, the aim was to give to this part of the vault a more uniform appearance. This led to trace all the springing of the arches —up to the level of the spandrel — with the same curvature. This technique was managed by drawing arches of four-centred arches, causing the spandrel to take the shape of a solid revolution. This eventually gave way to lierne vaults (Willis, 1842, 25–28). Finally, the fan vault was generated by the rotation of a single arch from each spandrel (Willis 1842, 44).

Those changes transformed also the relationship between ribs and webs above the level of the spandrel. The relationship between apparent and real construction was changed, the place of the "web" became progressively colonized by pieces where a portion of the rib and the adjacent web is made of one single piece of stone. This process ended in the fan vault, a solution in which the discordance is absolute: the actual construction is a solid work of stereotomy; the apparent structure is one of ribs and web (Willis 1843, 28–29).[15]

The global vision could only have been described by someone with the fundamental assumption that we must look closely at the differences between actual and apparent construction. It is a story of the dialectical relationship between these two options. As he said: "and so by gradual degrees the mechanical and decorative construction of the vault, which began being identical, ended by becoming totally different" (Willis 1842, 43).

As just mentioned, Willis showed that each step can be described geometrically. Inspired by the heuristic assumption that certain rules governed the Gothic methods, Willis was able to identify a first generator scheme for lierne vaults. Diverse solutions were reached by simply moving the centers of the different arches. Willis assumed that in England —unlike what happened on the continent — those centers could rest above or below the line of impost (Willis 1842, 21–22).[16] As Willis demonstrated, the contrasting aspect of the vaults of the cloister of Norwich cathedral may be offered as a visible proof —in a single building — of the changing effects of using this generator scheme (Willis 1842, 61–69). This was as well a relevant finding because, as he suggested, the recognition of a set of rules would be used to spot local schools and historical stages (Willis 1843, 24).[17] Willis's following achievement in this search for rules was to define the geometry of lierne vaults and fan vaults.

A good scientist as Willis knew that all these assumptions needed to rely on very accurate data. This pointed at the future importance of rigorous surveys to hold a history of the construction procedures and proposed techniques for surveying. This is why he even recommended some surveying techniques and techniques (Willis 1843, 62–63).[18]

Drawing as a tool for Willis' heuristic approach.

With the guidance of these heuristic concepts, Willis had to investigate, to penetrate "virtually" the mass of the vault construction without physically removing it. For this undertaking drawing would become an essential tool. In accordance to those principles, Willis had to appeal to ways of drawing adapted to several difficult and specific tasks: to locate where the hidden parts in the construction of a vault were at a variance with the apparent ones, and explore them; search the underlying rules and geometry of the different types of vaults and their relationship among them; express the aesthetic effect of playing with this rules; and virtually extract from their body some relevant pieces rigorously defined.

What follows is a review of some of these kinds of drawings. As we shall see, he often leaned on relatively recent innovations, some of them at the reach only of a very well informed researcher. Even in some cases he employed an ad-hoc solution devised by himself.

Recollecting information. Identifying the apparent and actual construction.

Willis discovered that the first thing to do when the apparent construction and the real one don't seem to match is to take exhaustive details and notes. In the case of a vault it was then necessary to inspect it from below and from above, taking into account not only the soffit, where the "apparent construction" is displayed, but the back side, looking for traces –such as real lines carved on the surface– which would help to deduce the actual construction. Notes, sketches, partial views and measured plans needed to be made.

The first time Willis accessed the back of a lierne vault or a fan vault he must have felt impressed by their strange "topography". However, he had not been the first person to observe them. Publications by Augustus Pugin, or John Britton reflected both sides of the vaults so convincingly, with such a thorough recording of joints and precise measures, as to be taken by Willis as reliable sources when needed.

It is interesting to note that the high quality of these drawings seemed to respond —at least in the case of Britton— to a deliberate attempt to reach the same level in the representation of Gothic architecture than that devoted to Greek architecture by the editions of the Society of Dilettanti. Willis was thus benefitting from high levels of precision that were —as Britton pointed out— the merit of a new generation of draughtsmen (Britton 1819, v).[19]

Especially striking for their anatomical character were Mackenzie's drawings of the vault of King's College, made to illustrate the interesting comments by Pe-

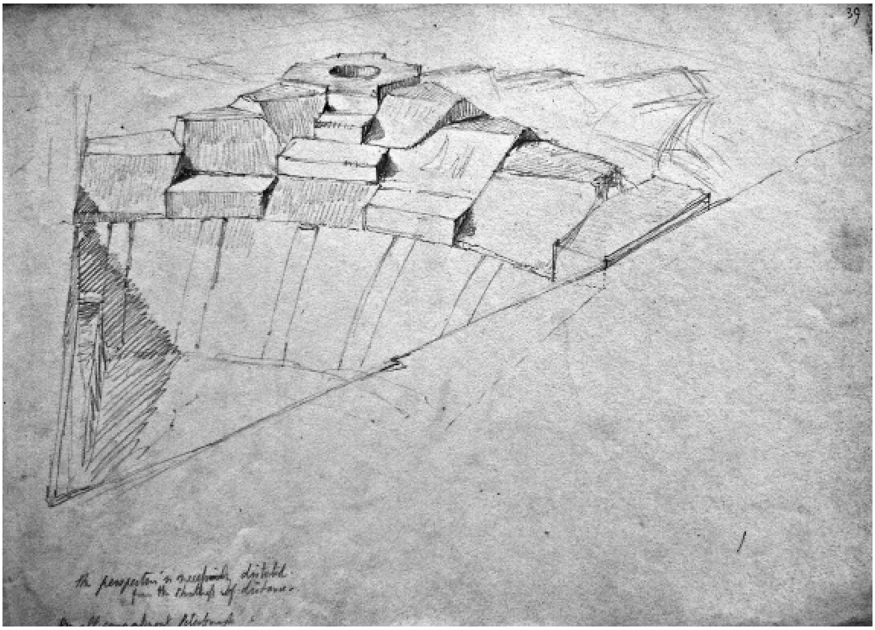


Figure 1
Willis's sketch of the back of vault in Peterborough Cathedral (CUL, MS Add. 5138, 39)

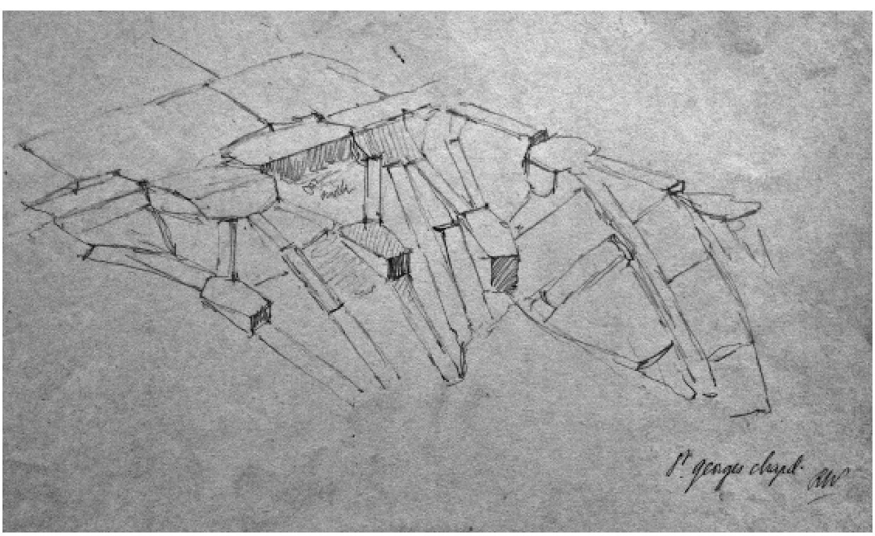


Figure 2
Willis's sketch of the back of vault in St. George's chapel, Windsor (CUL, MS Add. 5138)

ter Barlow. This text, which was published just a year before and cited by Willis, deserves closer examination (Tredgold 1840).[20]

Nevertheless, Willis would be the first to interpret the system of construction related to the peculiar forms surveyed. Among all of Willis' sketches, we may distinguish two types. On one hand, we find those showing partial views with a low point of view which would have been taken on place, rendered with remarkable quality which, and as Willis carefully noted, unavoidably "distorted" the real measures. On the other hand, there are measured partial plans and sections.

It does not appear that these drawings were intended as a private recollection, not to be published. (For this he will prefer for reasons we will discuss later isometric views).

One of the most striking sketches, because it anticipated somehow one of Viollet-le-Duc's spectacular strategies of drawing, is the "exploded view" of the small Peterborough's vault. It is not easy to find a clear precedent for this "virtual" anatomy —considering its clear spatial order and how their detached pieces are separated from one another while maintaining its relative position in space. Not found even among the drawings on Greek construction mentioned above.

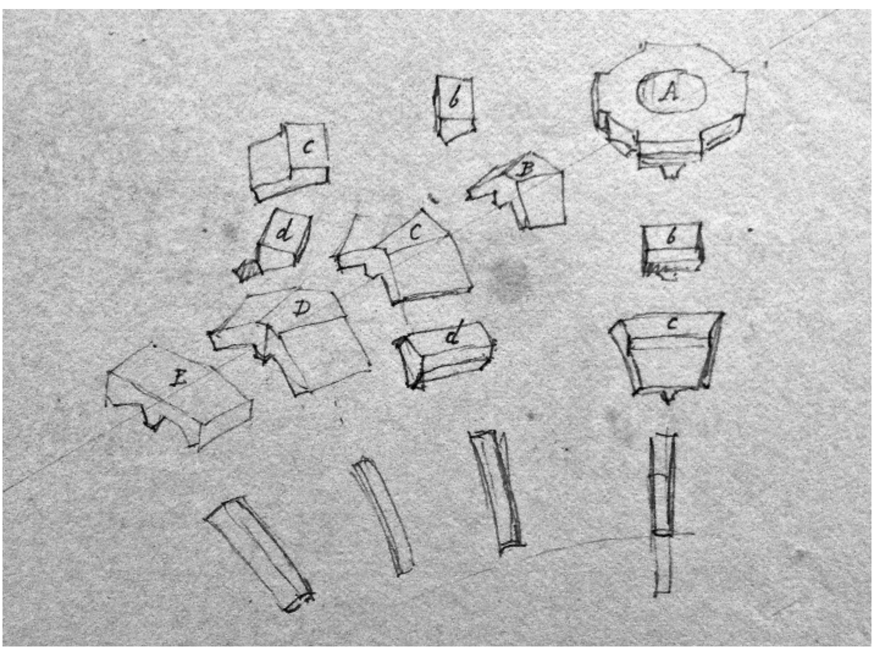


Figure 3
Willis's exploded view of a small vault in St. Ptereborough Cathedral (CUL, MS. Add. 5138 not n.)

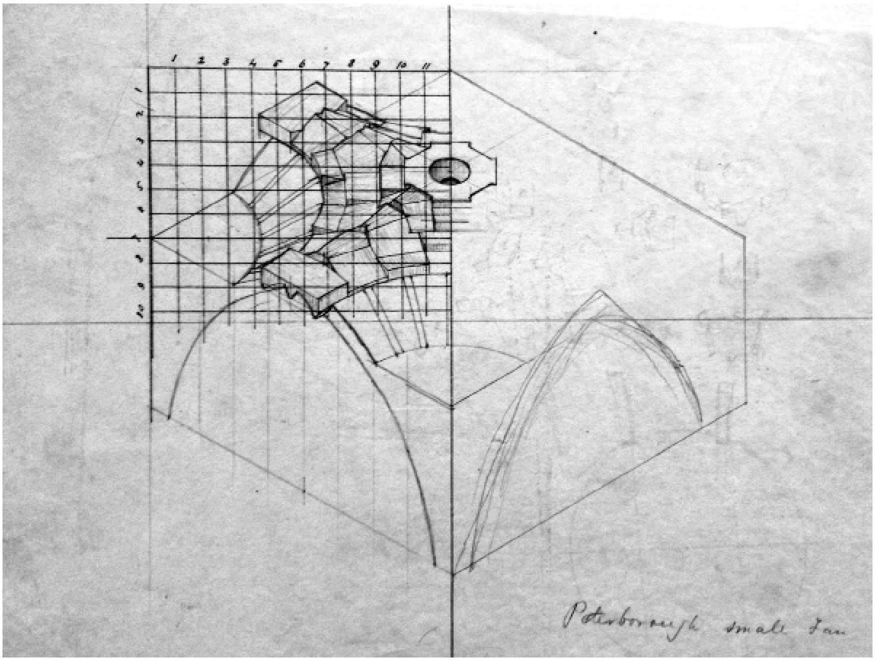


Figure 4
Isometric. Preparatory drawing of Fig. 3 (CUL, MS. Add. 5138, 79)

Willis finally arranged the edited plans in such a way so that it was easy to compare the soffit and the back of a vault, that is, to compare the apparent and actual construction. As usually in Willis' drawings, everything in the illustration of the plans of the vaults of Peterborough, St. George's chapel of Windsor or Henry VII chapel of Westminster seems to have been thought of carefully. For instance, while the soffit's plan usually was limited by straight lines, the limits of the plan of the back side follow the contour of each piece —the "real construction". (Willis, 1842, plate I).

More difficult to observe and figure out by observation alone was the actual inner construction of the "tas-de-charge". Willis' sketches of the transept of Westminster's vault are taken from different points of view trying to cope with it, and noting some doubts about the disposition of the web's filling masonry courses. An issue that in the final version remained unsolved and —we may say— Willis got round: "It is remarkable that the courses of the vaults are not laid level, but are in most cases made to incline downwards upon the diagonal rib...What might have been the reason for this downward inclination of the coursed it is not

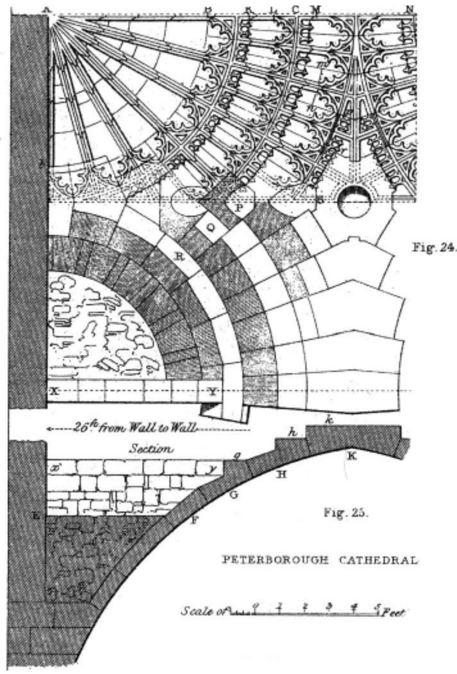


Figure 5
Simultaneous representation of the soffit and the back of the vault of Peterborough Cathedral. (Willis 1842, plate 1, fig.24)

easy to say" (Willis 1842, 8–9).[21] But as we will see later, this precise feature will have great importance in the critical reception of the article in France (CUl, MS. Add. 5138, not n.).

In the case of the spandrel as "tas-de-charge", the investigation may have been somehow stimulated by other previous drawings visualizing its presence. In Rondelet's treatise on construction there was a plate of a Gothic lierne's vault in which we see the arches springing from a solid acting as "tas-de-charge". The drawing could have acted as a starting point for a more in depth inquiry. What in Rondelet's drawing is but a blank undetermined area, should have a specific form of construction (Rondelet 1830–32, tome 6, plate XLII).[22]

Willis final drawing displayed two realities: the side on the left is a perspective showing the appearance of the vault, while the side on the right shows a section, giving insight into its constructive reality. This drawing, as we will see later, would provoke many reactions in the future (Willis 1842, 6, fig.3).

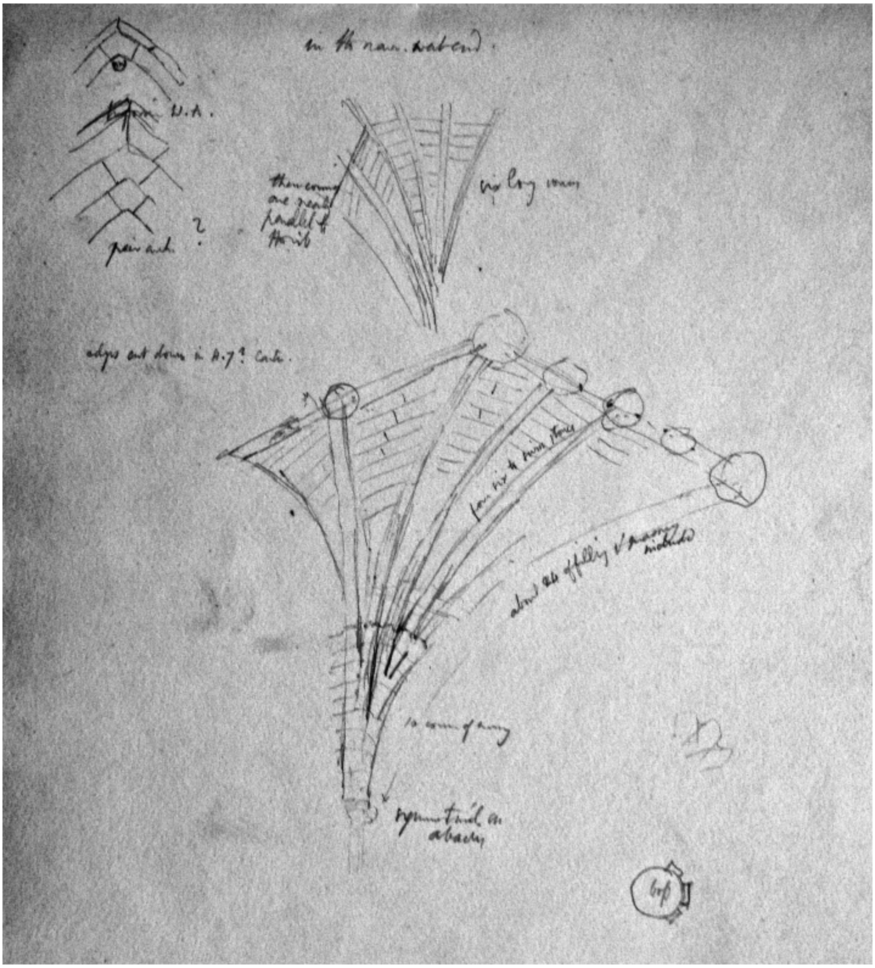


Figure 6
Willis's sketches of the "tas-de-charge" and web of the vault of the south transept of Westminster Abbey (CUL, MS. Add. 5138 not n.)

Collecting evidence

This drawing was based on tangible material evidence, which confirmed the assumed separation between apparent and actual construction. Eventually, Willis was able to find the equivalent to those scattered remains so useful for understanding Greek construction and to have the opportunity to examine them carefully. He was fortunate to inspect the remains of some takedowns of a Gothic

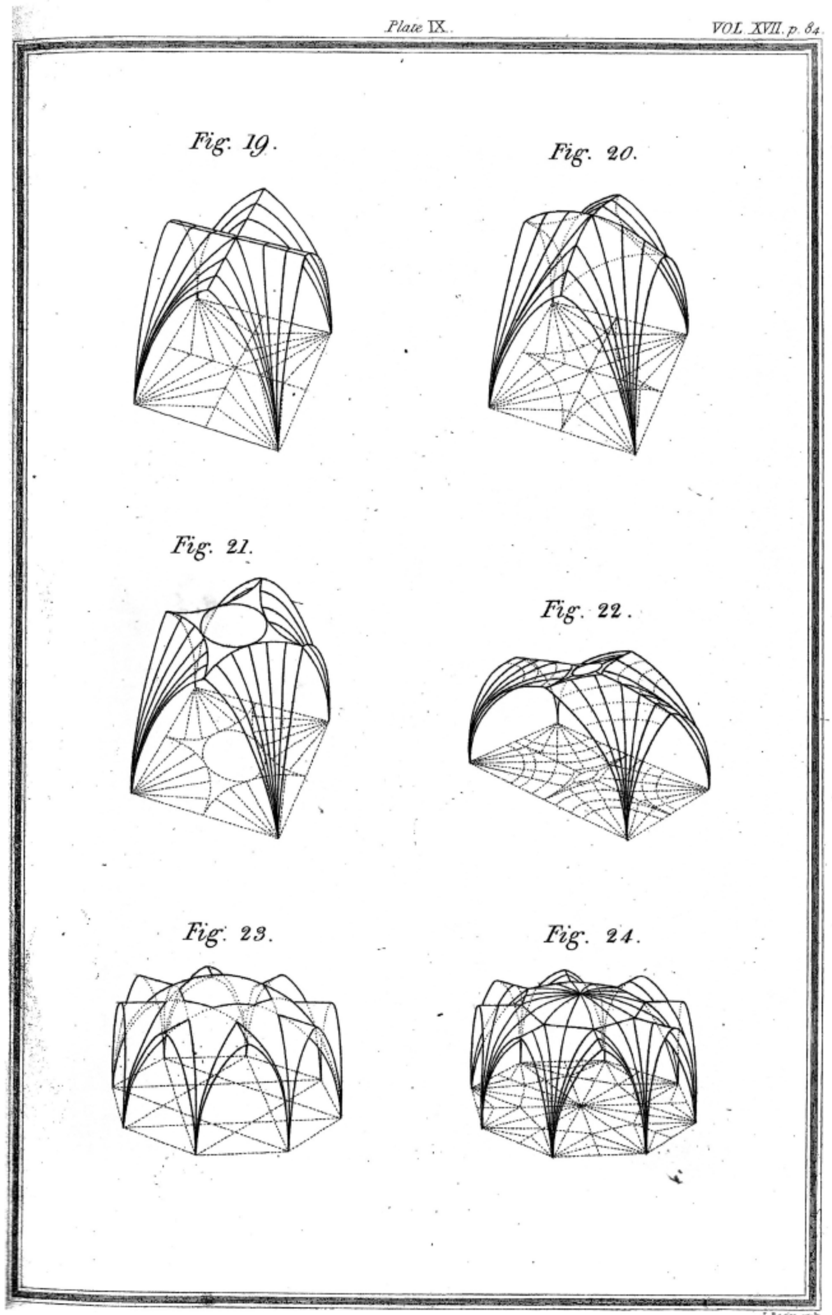


Figure 7
Some diagrams of vaults from S. Ware (1818, pl. IX)

building: the aisle vault of St. Saviour's Church in Southwark —demolished in 1839— and the vault in the northwest section of the nave of Canterbury Cathedral would provide valuable samples. Two ashlars pieces of spandrels from different periods agreed with the cantilever scheme. Willis observed also bearing both onto their upper horizontal surfaces carved lines corresponding to the use of templates, and imagined also how those pieces were dressed by the mason. (Willis 1842, 10 fig.6; 12 fig. 7).

Geometric law of generation and Ware's diagrams.

To successfully undertake another of his heuristic hypothesis, —there were geometrical rules for the vaults—, Willis seized on a diagram which was an invention of a man of the previous generation, Samuel Ware. "In his admirable trea-

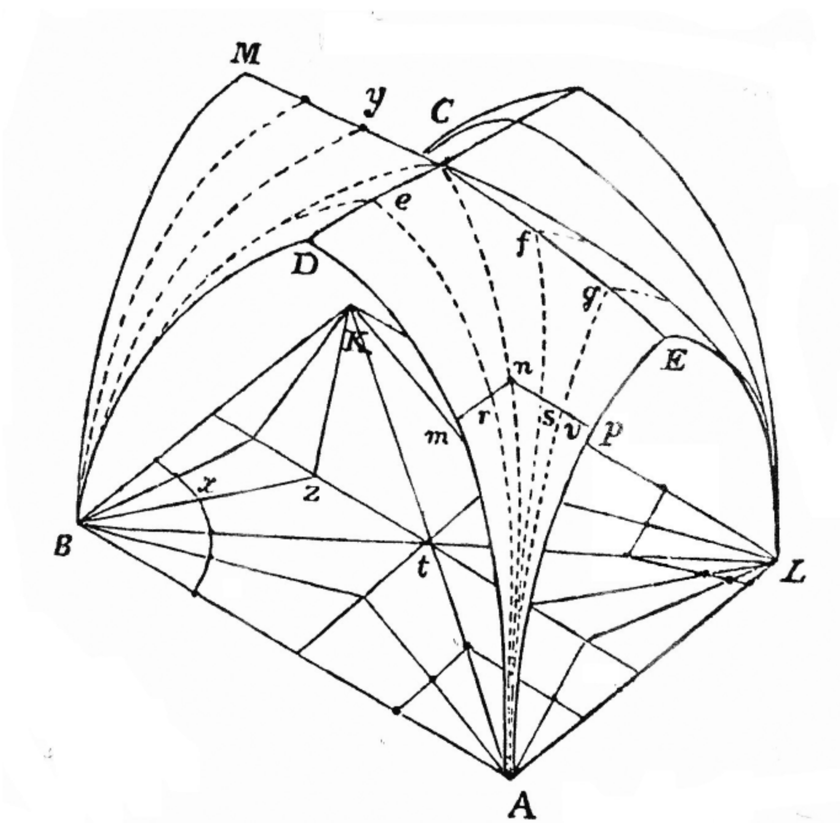


Figure 8
Comparative diagram of two types of tierceron vaulting. (Willis 1842, 14, fig.9)

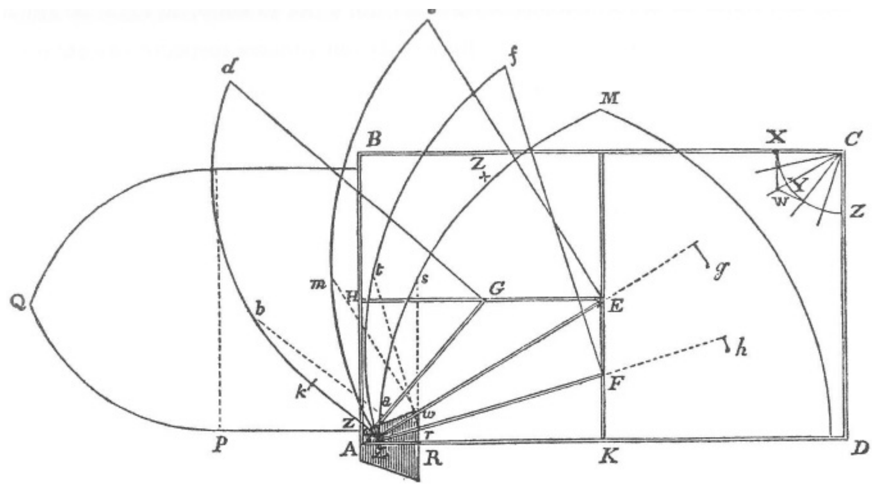


Figure 9
Willis diagram showing the independence of the curvature of each arch (Willis 1842, 19, fig. 10)

tise", he displayed a first gathering of the many forms a vault can take, from "Classic to Gothic" (Ware 1818). Ware used schematic "wire" drawings in which all decorative motives were eliminated. Only their mere geometry was represented (Ware 1814, plates 6–9).[23]

Willis used a diagram similar to one of them. It served to represent the difference between the French and the English vaults (Willis 1842, 14, fig. 9) Now Willis had to explain how from this generic vault, a geometrical play may generate many alternative solutions for an English vault. Willis guessed he could use French treatises on stone cutting techniques to trace back the ancient practices. Specially the one by Philibert de l'Orme's. Being the oldest, it was likely to echo medieval techniques he had known (De l'Orme 1568). In fact De l'Orme described an example of a Gothic vault in which "every rib is entirely independent of the others in its curvature" and is composed of "a single arc of a circle whose centre is upon the impost level"", starting conditions that Willis assumed were the same in England. (Willis 1842, 21)

To generate the different solutions Willis adopted from De l'Orme another graph in which all arches are abated onto the plan, a display still currently used in works on stone cutting —although he advises it doesn't mean it was used as such in the Middle Ages— (Willis 1842, 23).

Taking into account that the central points of the arches may be situated in many positions above, on, or under the impost line, it was possible to create

many combinations of tierceron's vaults. Implicitly, this meant that the French scheme was more rigid —as the centers of the arches remain on the line of impost— while the English scheme was more flexible and productive.

How to show how geometrical rules have an aesthetic impact: contour lines

Now, what mattered to Willis —after having visualized the geometrical rules— was to find a way to display the aesthetic effect of the different solutions generated by playing with them: The heuristic principle implying that changes on the vault's geometry —and therefore in their form— could be associated with shifts on the aesthetical appreciation demanded also a form of visualization.

How could this be expressed? With great ingenuity, Willis proposed a simple operation: to cut the vault by a horizontal plane, at half of its height, —coinciding thus approximately with the upper surface of the solid spandrel— and delineate the resulting outline on one of the corners. Suddenly, for each vault a characteristic shape emerged —depending on the particular geometry of the arches

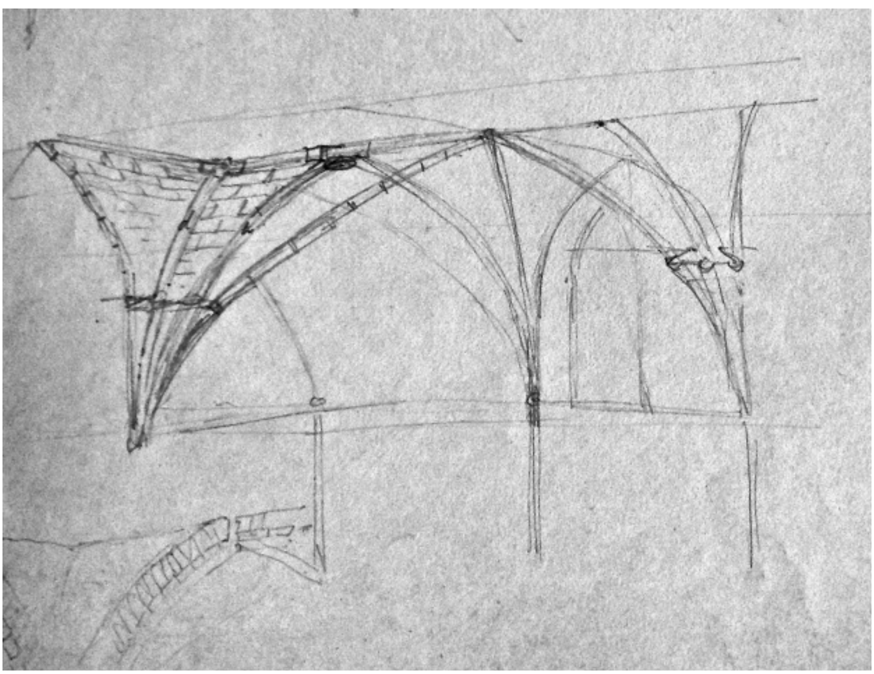


Figure 10
Willis's sketch of a vault cut by a plane passing over the spandrel (CUL, Robert Willis Papers, MS. Add. 5138, not n.)

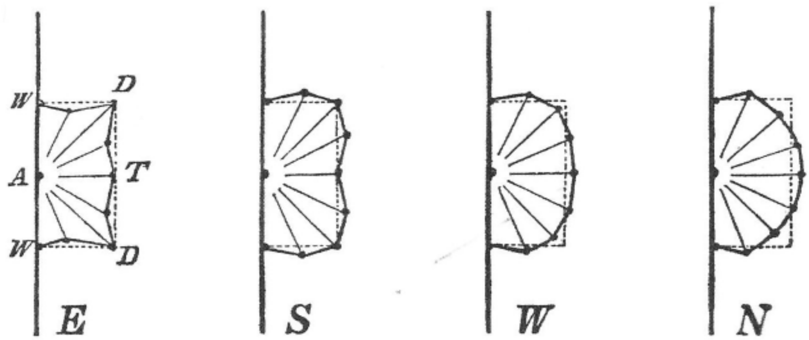


Figure 11
The form of the middle plans of the spandrels in four selected vaults of the cloister of Norwich Cathedral (Willis 1842, 65, fig.33)

springing from the spandrel— which made evident the differences between vaults that might look similar when seen in plan. The result of applying this method to the vaults in the cloister of Norwich Cathedral is very telling. (Willis 1843 , 65 fig 33).

The process can even be generalized: by making several equidistant parallel sections from the impost line to the crown of the vault "the resulting lines upon the plan will form a species of shading that will show the exact nature of the entire form, such in the same manner as the topographical shading of mountains and broken ground in a survey is made to represent their exact solid figure upon the mere plan" (Willis 1842, 67–68). This drawing allows the general disposition of the surfaces "to be recorded with sufficient accuracy" which is to Willis of great importance taking into account "the effect of theses dispositions upon the aesthetic character of the vault" (Willis 1842, 67–68).

That is, Willis applied to the vault the system of contour lines. The relative novelty of this operation for an English reader must be underlined. This procedure —rediscovered many times along the eighteenth century— was relatively new and limited to territorial maps. Adopted by the French land registry in 1818, only in 1838 had it been introduced in England and Ireland and just for the purpose of survey at a big scale, as Butler J. Williams reported in his book of Geodesy (Butler 1842). He also noticed that by then it was timidly beginning to be proposed in England as a system available also for smaller plots.

In a review in a magazine of this work, it was said that "the chapter on Hill Drawing opens up a subject almost entirely new to the profession in this country" and believed necessary to explain that his tracing was grounded on geomet-

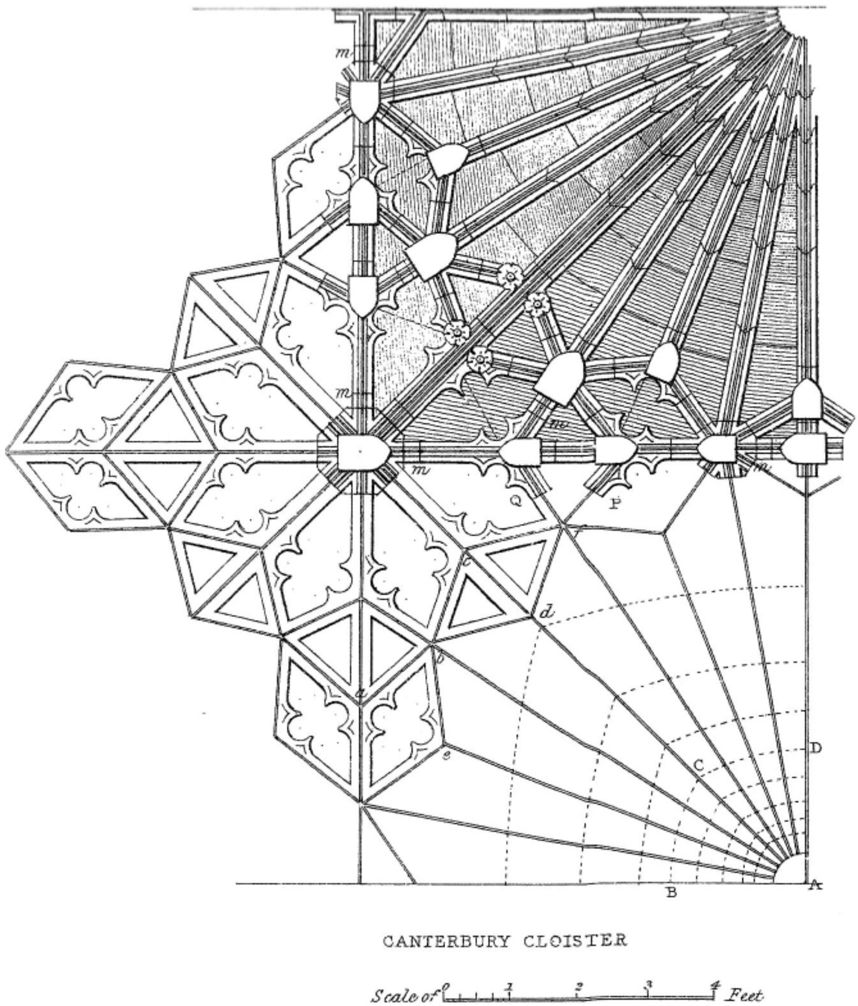


Figure 12
Vault of the cloister of Canterbury. Bottom, right side: contour lines describing its real form (Willis 1842, plate I, fig.15)

ric basis, and not as "as some have supposed according to the mere dictates of taste" (Anon. 1842, 176). Thanks to his extensive technical knowledge Willis was familiar with this kind of representation, he could have consulted without difficulty its fundamentals in publications such as Puissant's *Traité de Topographie* (1779) or Leroy's *Descriptive Géometrie* (1834, I: 379–90, II: plate 59–60),

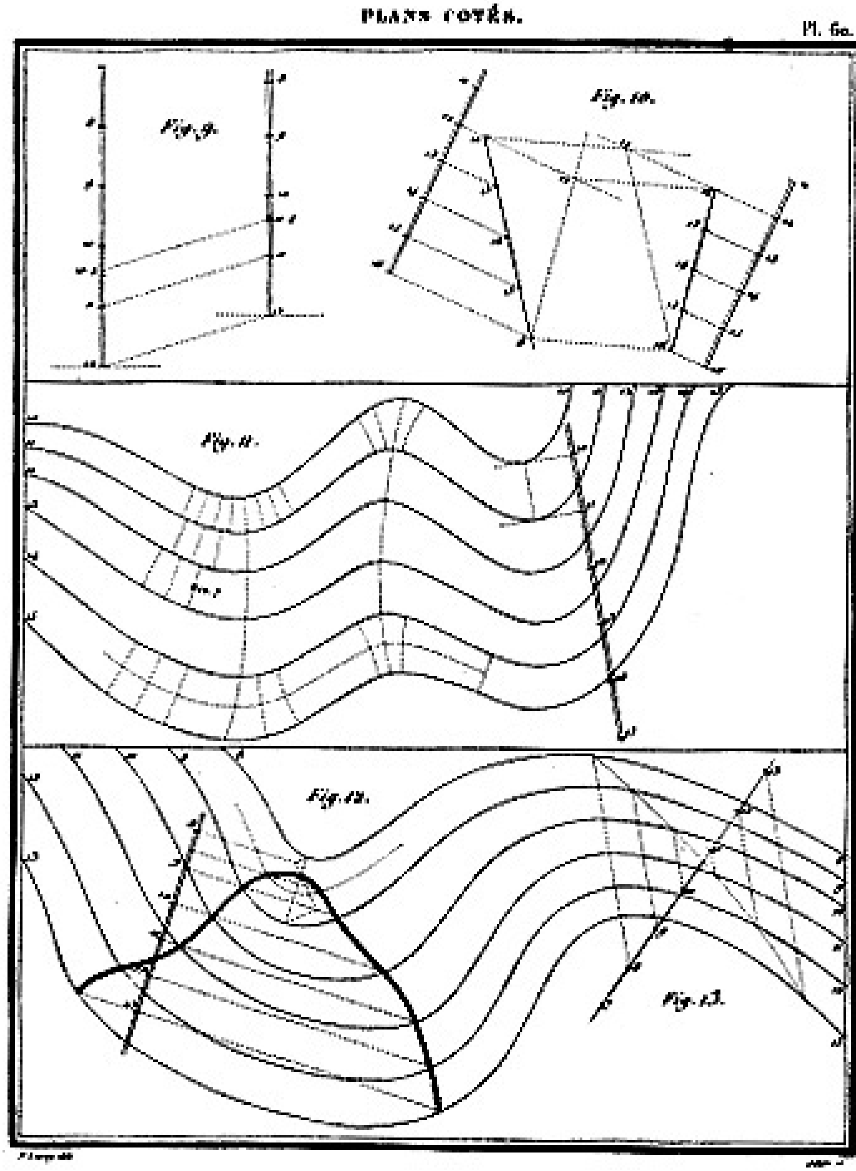


Figure 13
Contour lines in Leroy’s Descriptive Geométrie (Leroy 1834, pl.60)

which appears in his library (Hodgson 1872, 45). But probably many of his readers were not so at ease with this peculiar invention.

How to dissect the vault: the "virtual reconstruction" of each piece using Descriptive Geometry methods

What was lacking was to solve the most difficult task: to find a way to "see inside" the vault without dismounting it, and to imagine the process of construction. How each piece was defined, especially those pieces with a higher degree of complexity, such as the boss stones where several arches meet?

To "calculate" this, Willis resorted to the methods of Descriptive Geometry. He surely knew the work of Monge, at least his treatise on machines, quoted in his *Principles of Mechanism* and also the above mentioned *Descriptive Géometrie* by Leroy (Willis 1841, vi–vii; ix, xiii). It must be said that when Willis re-

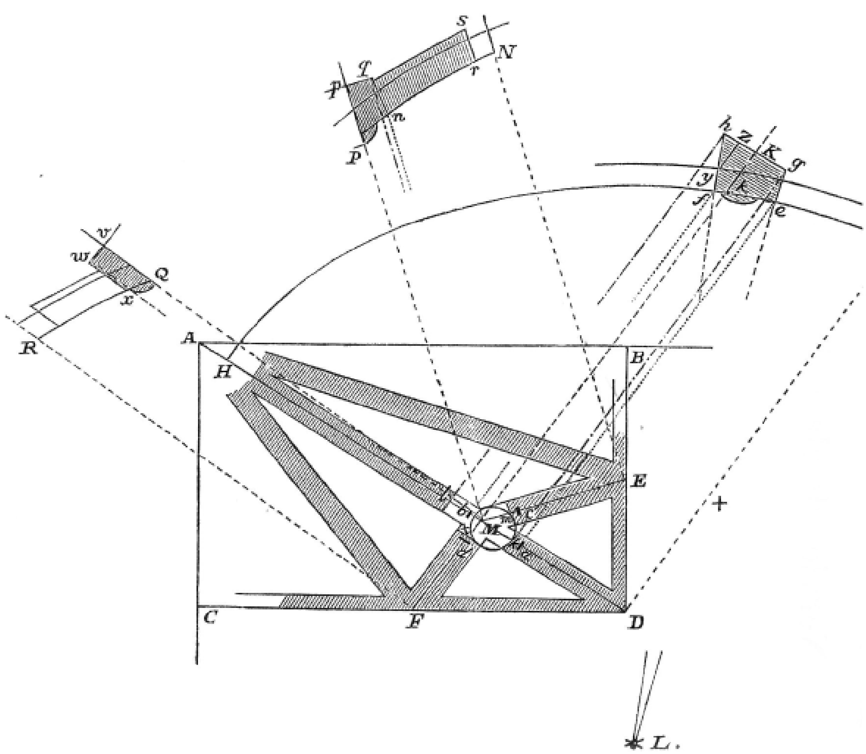


Figure 14
Definition of a boss in a lierne vault (Willis 1842, 32, fig.13)

ferred to his use of methods of descriptive geometry, only a select group of readers could really understand what he meant, because at that time there was barely any English book on the subject. Just one year before Willis' article appeared, the modest *The Elements of Descriptive Geometry* by Thomas Garinger Hall was used as a manual for students. The subject was "unknown as a branch of instruction" before the lectures in the Engineering Department of King's College in London started in 1839 (Garinger 1841, iv)

It is not necessary here to go into much detail about the operations expressed in this figure (Willis 1842, 32, fig. 13). Willis proceeded to define the form and measures of the stone piece, and deduce the sequence of cutting operations that could have given to a rectangular block its final shape. The horizontal upper side of the block had been used as a "surface plane of work" useful to plan the rest of the operations. This face, not being visible from inside de nave, didn't need to be

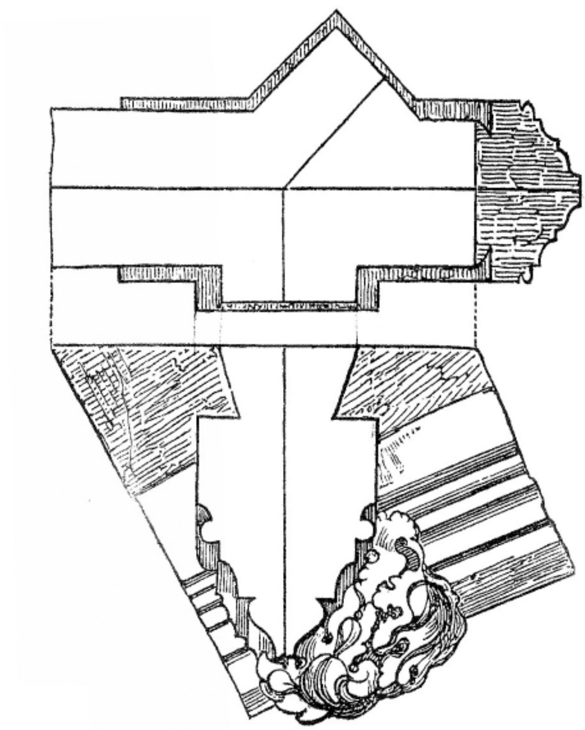


Figure 15
Boss of Canterbury Cathedral showing lines on the upper surface traced by a mason (Willis 1842, 35, fig.14).

carved. This is a theoretical method: the use of "the last possible amount of descriptive geometry that is warranted by the remaining evidences" (Willis 1842, 36) provides a piece equal to those found —as the boss of Canterbury Cathedral where marks of the process in the upper surface may be found and explained the peculiar form of the back of the vaults (Willis 1842, 35–6, fig.14). Anyhow, Willis wisely argued that this was a theoretical reconstruction, based on a modern method, and suggested also a simpler method akin to the geometrical knowledge of the medieval stonemasons. (Willis 1842, 36–38).

In its purpose —to describe a selected piece extracted from the vault— this drawing recalls the plates of many modern French treatises on stereotomy. In Rondelet *Art de bâtir* —mentioned occasionally in Willis's manuscripts— and in Derand (1643), Frézier (1739) and La Rue (1728) treatises —all of them cited in the article— (Willis, 1843, 21) it was also common use to describe the detached piece in three dimensions, as Willis did in a similar drawing depicting Peterborough's vault (Willis 1842, 47 fig. 21).

How to show the actual construction of the vault in three dimensions: isometric drawings.

At the end of his research, Willis wanted to present a three-dimensional view of the back of some lierne and fan vaults. He wanted to reveal this strange landscape that was the key —unseen from below— to understand the real construction of those vaults. If possible, in the more objective way, and from a position that —as he warns on a note on one of his *in situ* sketches— would not distort the measures, unlike what happens in perspective.

He was looking for a "representational method of drawing", a method not meant to take data" from reality (as freehand sketches are) but aiming to "produce" and "build" a drawing from data previously recollected, usually in plan and section.

For this kind of representational drawing there were in England two methods. One devised and Nicholson (1840), which consisted of parallel oblique projection, and the earlier William Farish isometric system (1822), much more practical. At the time, when Willis used it, it was beginning to be accepted in the representation of architecture. It appeared frequently in popular publications on gardening and rural villas by John Claudius Loudon, an enthusiast of the system.

Willis adopted Farish's solution (Willis 1842 plate.2–4). In Willis papers some preparatory drawings are found in what clearly seems "cabinet" work (CUL, MS Add. 5138, 63). Isometric representation had clear advantages, but there is one practical side Willis would have appreciated very much: how easy it was to trace circumferences in the three directions of the space (or onto the faces

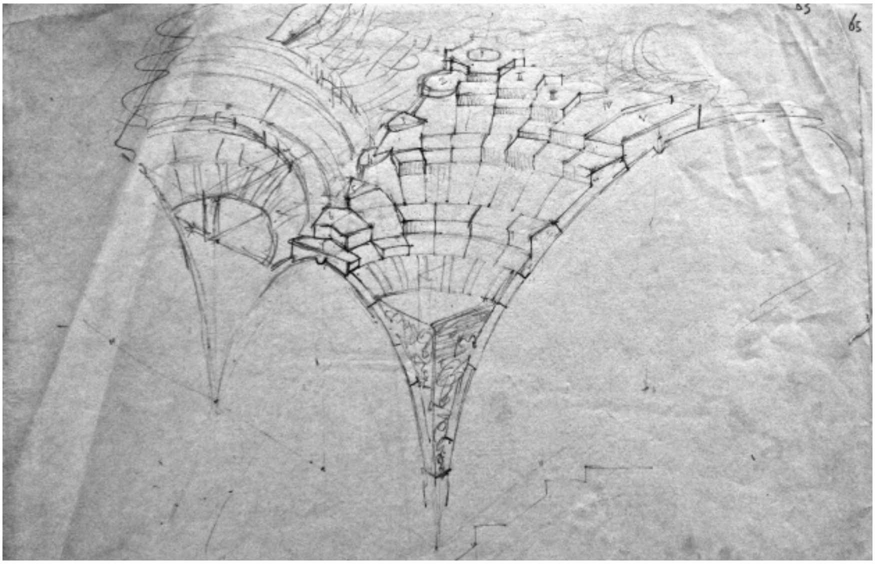


Figure16
Willis's "almost isometric" sketch of a vault on the east side of Peterborough Cathedral (CUL, MS Add. 5138, 63)

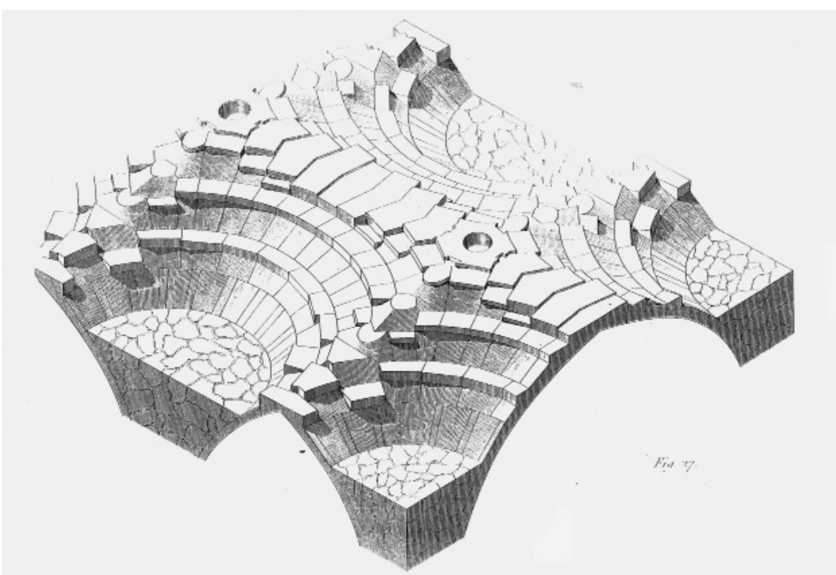


Figure 17
Its final isometric version (Willis 1842, plate2)

of a cube) Each circumference is represented always by the same ellipse, and hence —what is good news for the draughtsman— to a family of concentric circumferences corresponding to a single family of ellipses, which may be drawn in a prefabricated template, as illustrated in a plate by Farish.

With this template, three-dimension drawing of machines with gears and wheels of different size and positions was then greatly simplified: no other system of projection could solve this problem better. Willis cleverly saw that the problem of drawing vaults in three-dimension was quite similar. In the end, all arches were segments of circumferences (or composed by them) and the plan of fan vault is a

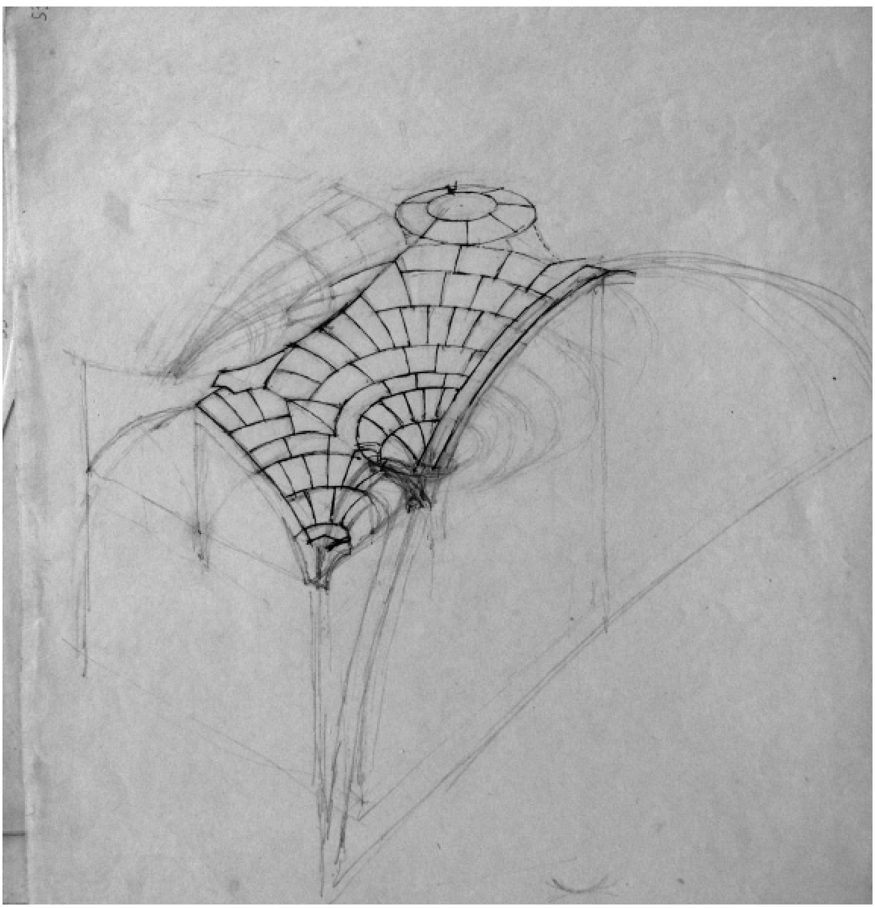


Figure 18
Willis's "almost isometric" sketch of Henry VII's Chapel, Westminster (CUL, MS Add. 5138, 53)

composition of concentric circumferences. With a Farish's template, the drawing of those complex vaults was easily managed (Farish 22, figs. 5–7).[24]

The task could even be accomplished by using ad-hoc drawing instruments. A few years earlier, in 1839, Thomas Sopwith, author of *A Treatise on isometric drawing*, had submitted an instrument called Isograph, which drew isometric from the orthographic projection of drawings. This invention could catch the attention of Willis, being himself a creator of technical instruments.[25]

There is also a remarkable feature in the finished drawings by Willis: their delineation, how they are cut out to show how thooded walls and vaults would bond with the rest of the building. This an expressive form of drawing with many precedents: it appears for instance in Poldo's Temple de la Fontaine à Nîmes (1560), —which figured in his library (Hodgson 1872, 49)— in Perrault's Basilica (1673) (Hodgson 1872, 65) or in several Frézier plates (1754–1769). In adopting this for a scientific virtual anatomy of a construction, Willis anticipated Viollet-le-Duc idiosyncratic way of cutting.

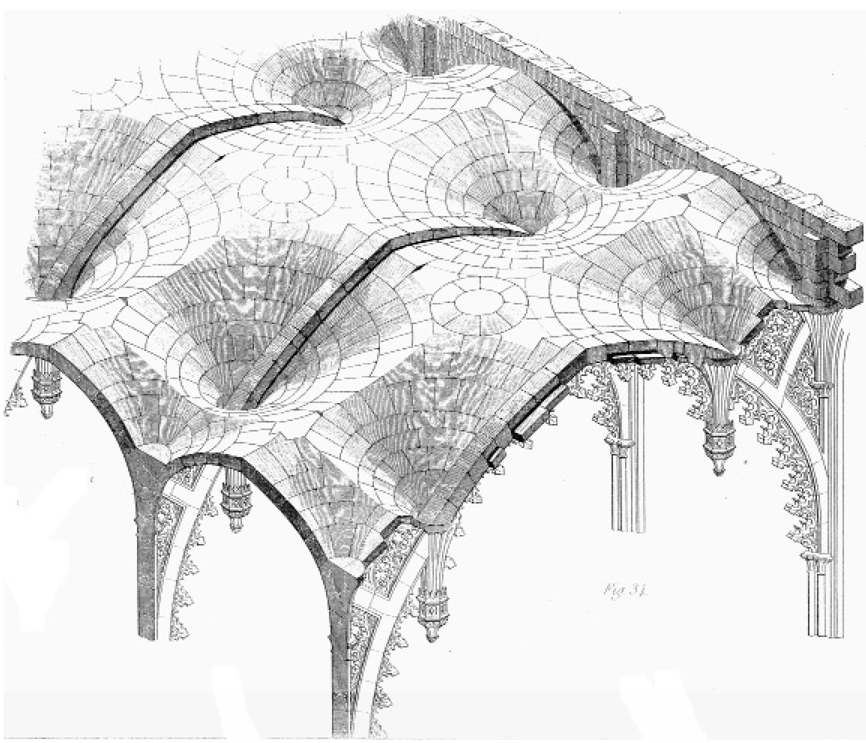


Figure 19
Final isometric version (Willis 1842, plate.3)

The reception in France. Viollet-le-Duc's focus on Willis weak point: the vault's web

The first article on construction of Viollet-le-Duc (1843–7) compared to Willis's (1842)

Willis's article on vaults had an immediate impact in France. Thanks to a fortunate circumstance: the director of the most influential magazine of Architecture, the *Revue Générale de l'architecture et des travaux publiques*, César Daly, was an architect with strong connections with England and a perfect command of the English language, as he had lived his childhood and adolescence in London. He had found the article perusing the first number of T*ransactions of the Royal In-*

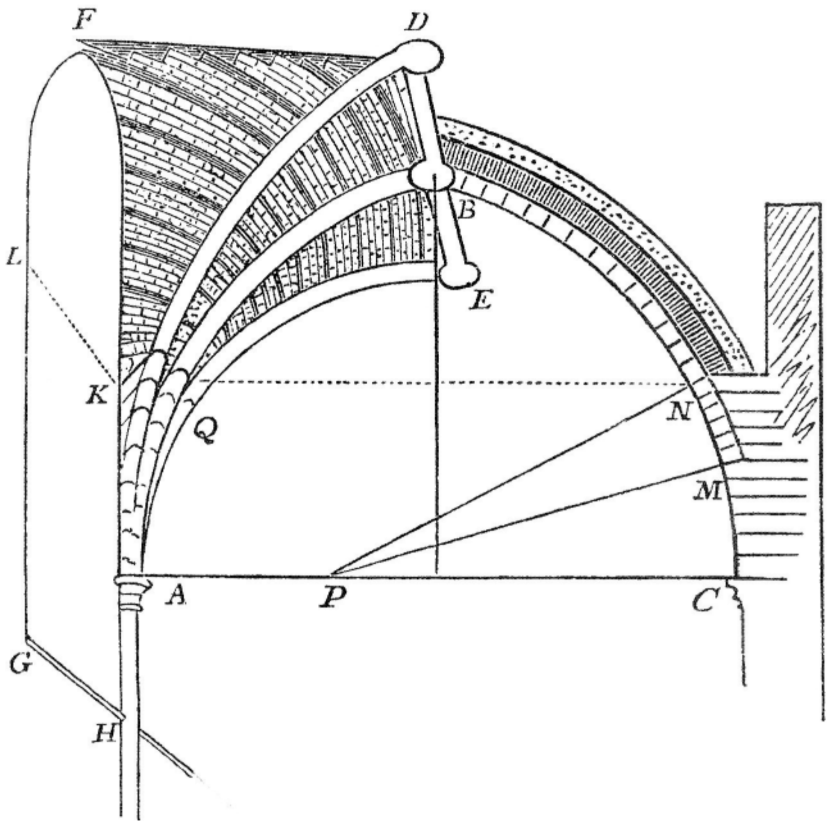


Figure 20
Diagram of the south transept of Westminster Cathedral showing both the "tas-de-charge" solution and the web courses (Willis 1842,6 fig. 3)

stitute of British Architects he had received. Deeply impressed, he decided to translate it right away. The translation appeared in the magazine's issue of 1843 (Daly 1843).[26] To the original drawings, reproduced with minor changes, he added two more drawings from Pugin's *Specimens of Gothic Architecture*, which were mentioned in Willis's text.[27]

Next year, Eugène Viollet-le-Duc begun to wrote an important article on Gothic construction to be published in successive issues of *Annales Archéologiques*. There is no mention of Willis's work, but it is hard to believe that Viollet-le-Duc a man then in his thirties —and fourteen years younger than Willis— didn't had a look on Daly's translation (Viollet-le-Duc 1844–47).

Anyway, a comparison between the two articles may be interesting. Differences may be pointed out in the content: the scope of Viollet-le-Duc is wider, touching other aspects than vaults. And also in the heuristic main focus: medieval construction tended to a rational constant improvement. Hence visible changes of configuration may be explained by searching how the stability, efficiency and resistance of the construction were bettered by those changes. Which led Viollet-le-Duc to search the answer into the mass of the building, by way of virtual anatomies. Their methods were also unalike. Willis thought as a scientist, wor-

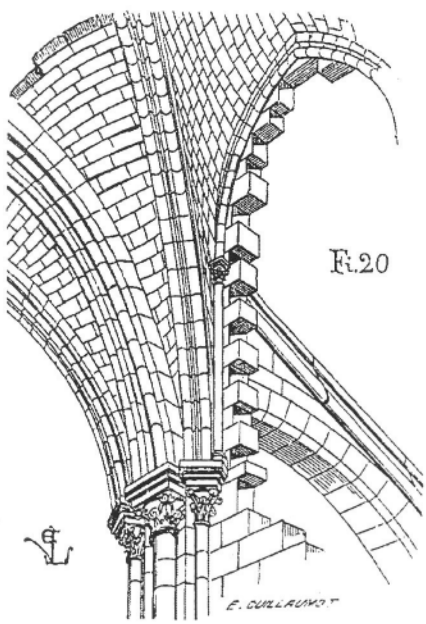


Figure 21
Viollet-le-Duc drawing of the springing of a vault and its web (1847 vol 6: 199, fig.20)

ried to provide, when possible, concrete evidences to confirm his hypothesis, creating instruments for surveying and eventually claiming for a collective effort. Viollet-le-Duc, confident on his own powers of penetration, after much private examination guided by his heuristic approach, simply asserted what he had de-

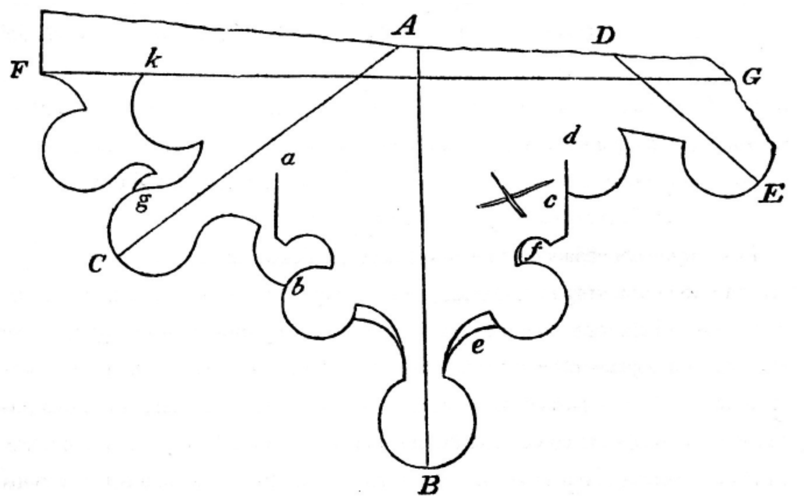


Figure 22
Spandrel stone from the side aisle vault of St. Saviours' Church, Southwark, with lines and marks of a mason on its surface (1842, 10, fig. 6)

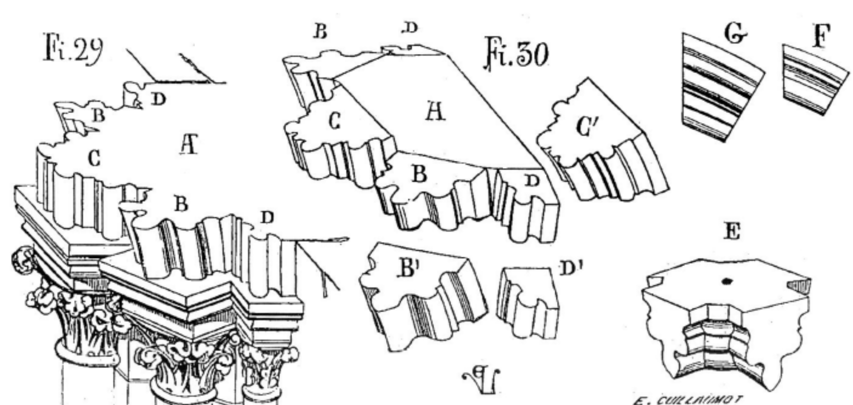


Figure 23
Viollet-le-Duc decomposition of a spandrel (Viollet-le-Duc, 1847, vol. 6: fig. 29–30)

duced. One taught how to inquire, the other tried to convince by the logic of his argument.[28]

But there were also some intriguing coincidences worth mentioning, especially in the section published in 1847 (vol.6: 194–205 and 247–255). Here Viollet-le-Duc used —as Willis did— wire diagrams to determine the geometrical rules of French vaults (vol.6: 197–8, fig.16–18). He also centered his attention into the springing of a vault (199, fig. 20). And with an illustration that may be seen as a blending of Willis's ones: it shares with the left side of Willis's drawing of the Westminster Abbey's transept the same point of view (Willis 1842, fig.3), and the toothed delimitation of Willis's isometric perspectives of fan vaults —such as in Sevenths chapel at Westminster plate— (Willis 1842, plate. III).

He also studied in depth the "tas-de-charge" (Viollet-le-Duc 1847, vol.6: 247–251). It is intriguing that Viollet-le-Duc paid so much attention to it, as its understandings didn't have for the history of French vaults the same explicative potential it had when explaining the transformations of the English vaults. Was he trying to emulate and overcome Willis in the analysis and expression of this particular point? Compared to Willis's drawings, his dissection of the inner construction of the spandrel by displaying the pieces composing it seemed a better strategy —although the unpublished exploded view of vault in Willis's manuscripts would compete with it— (Viollet-le-Duc 1847, vol. 6: 249, figs. 29–30). Viollet-le-Duc will come again on this issue, until arriving to its anatomical compelling versions in the *Dictionnaire d'Architecture*.[29]

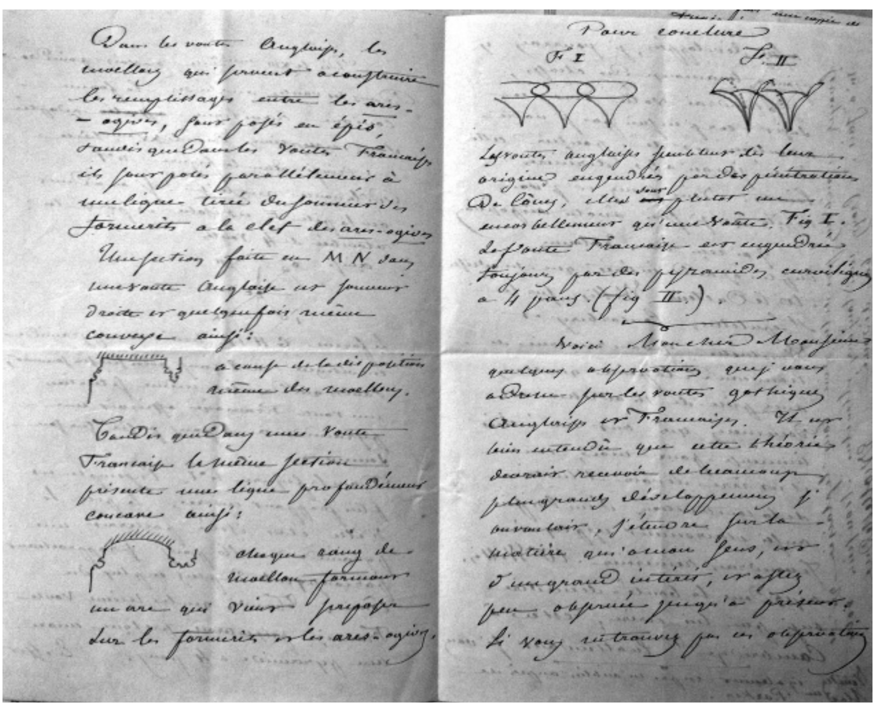
Comparing French and English vaults web. Parker correspondence with Viollet-le-Duc in Willis papers

There was great concern in Viollet's le Duc article on a question that Willis had eluded, his weakest point: to define the geometry and process of construction of the web between the ribs (Viollet-le-Duc, vol.6: 195–198). And this is something that mattered to much if we wanted to find the right place for the English vault in a comprehensive history of vaults, as he will prove in 1859 his article "Construction" in the *Dictionnaire d'Architecture*.

But it is interesting to point out, that the question of the differences between the construction of French and English vaults seem to have been already discussed by the two men around the 50's. In a letter found in CUL archives among Willis papers there is a letter by Viollet-le-Duc addressed to John Henry Parker in which he dealt —at Parker request— at length with this issue, signalling the main points to have in mind. This letter was accompanied by some drawings by the hand of Viollet-le-Duc, explaining the differences between both ways of vaulting, very similar to those he eventually published in the *Dictionnaire*

d'architecture (CUL, MS Add. 5135. 204).

Although this letter is undated, was probably written around 1850 as Viollet-le-Duc asked Parker to transmit to Willis his gratitude for the books he have sent to him: the Architectural History's of Canterbury Cathedral (1845) Winchester Cathedral (1846) and The Church of Holy Sepulchre at Jerusalem (1849)[30] Parker seems to have acted at this moment as a "postman" between Willis and Viollet-le-Duc. Member of the *Socité française d'archéologie*, he visited often France to attend the *Congrès Archéologiques de France* and stayed long periods of time in the country devoted to architectural tours.[31] Then he had the occasion to meet Viollet-le-Duc with some regularity. In another undated letter Parker told Willis that he was going to send him what Viollet-le-Duc has given him in relation to Notre Dame (CUL, MS Add. 5135, 196) Finally in a letter sent to Willis from Oxford of March 5, 1851, made an account of his attendance to the Congress organized by Arcisse de Caumont and his encounter with Viollet-le-Duc, who asked him to sent his greetings to Willis (CUL, MS Add. 5135, 201).[32]



Dans les voutes Anglaises, les
moellons qui servent à construire
les remplissages entre les arcs-
-ogives, sont posés en épis,
tandis que dans les voutes Françaises
ils sont posés parallèlement à
une ligne tirée du sommet des
formerets à la clef des arcs-ogives.
Une section faite en M N dans
une voute Anglaise est souvent
droite et quelquefois même
convexe ainsi:
à cause de la disposition
même des moellons.
Tandis que dans une voute
Française la même section
présente une ligne profondément
concave ainsi:
chaque rang de
moellon formant
un arc qui vient s'appuyer
sur les formerets et les arcs-ogives.

Pour conclure
Fig I
Fig II
Les voutes anglaises semblent dès leur
origine engendrées par des pénétrations
de cônes, elles sont plutôt un
encorbellement qu'une voute. Fig I.
La voute Française est engendrée
toujours par des pyramides curvilignes
à 4 pans (fig II.).

Voici mon cher Monsieur
quelques observations que je vous
adresse sur les voutes gothiques
Anglaises et Françaises. Il est
bien entendu que cette théorie
devrait recevoir de beaucoup
plus grands développements si
on voulait s'étendre sur la
matière qui à mon sens, est
d'un grand intérêt, et assez
peu observée jusqu'à présent.
Si vous ne trouvez pas ces observations

Figure 24
Letter to Parker from Viollet-le-Duc undated (c.1850) (CUL, Ms Add. 5135, 204)

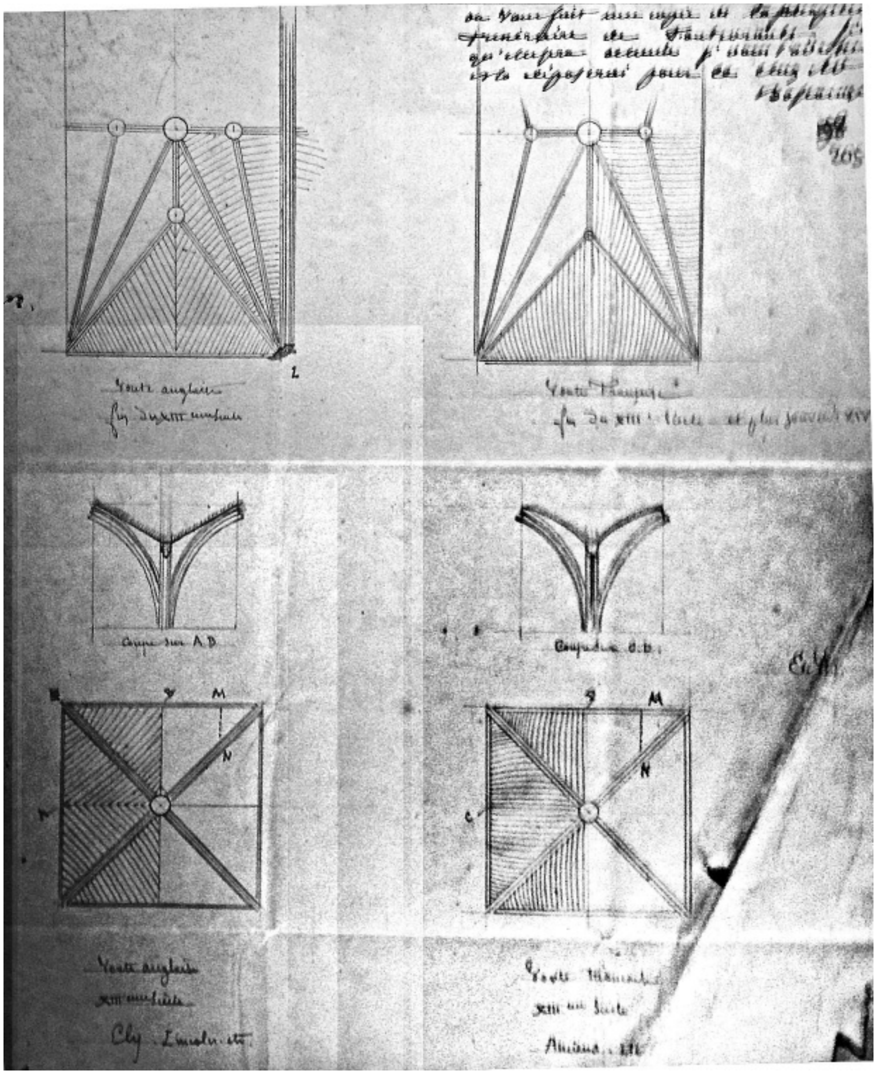


Figure 25
Viollet-le-Duc's drawings annexed to explain the difference between French and English webs (CUL, MS Add. 5135, 205)

Viollet-le-Duc first interpretation: difference on web's vaults meant diverse historical origin

During all those not yet well known exchanges matured Viollet-le-Duc matured his interpretation of the differences between the English and French vaults. His article on "Construction" in the *Dictionnaire d'Architecture* displayed similar drawings to those he had sent to Parker, and mentioned Willis for the first time, but just in a short note (Viollet-le-Duc, 1859). In this text he explained with some diagrams the contrast between the mode of construction of the web in the French vault and the English vault. Differences in the way of putting into place the masonry courses of the webs implied great differences on the geometry of their surface. He left clear how this was reflected in the directions the courses adopted in plan, and showed how crucial was to inspect this feature with close attention. Because, all this implied that even if French and English lierne vaults may look similar, they must have been developed from very different type of vaults in the past. The French had evolved from the roman groined vault, while the English must derive from those domical vaults of Anjou and Aquitain (English domains in Middle Ages) (Viollet-le-Duc 1859, 103–123).

But clearly Viollet-le-Duc had not settled the question. In the coming years the interest question of the relationship between English and French Gothic architecture would reach its peak, Parker being one of the most active in demanding its elucidation. Before Viollet-le-Duc volume of the *Dictionnaire* was published he had much insisted on its need in *An Introduction of the study of*

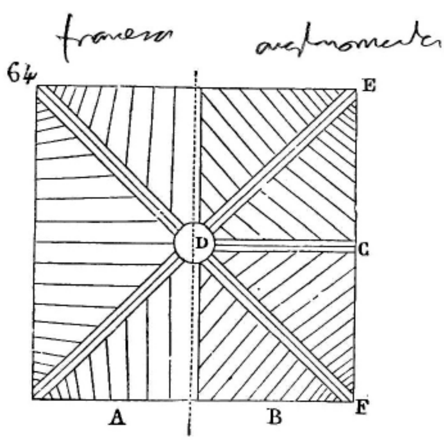


Figure 26
Differences reflected in plan between French and English webs (Viollet-le-Duc, 1859, 64)

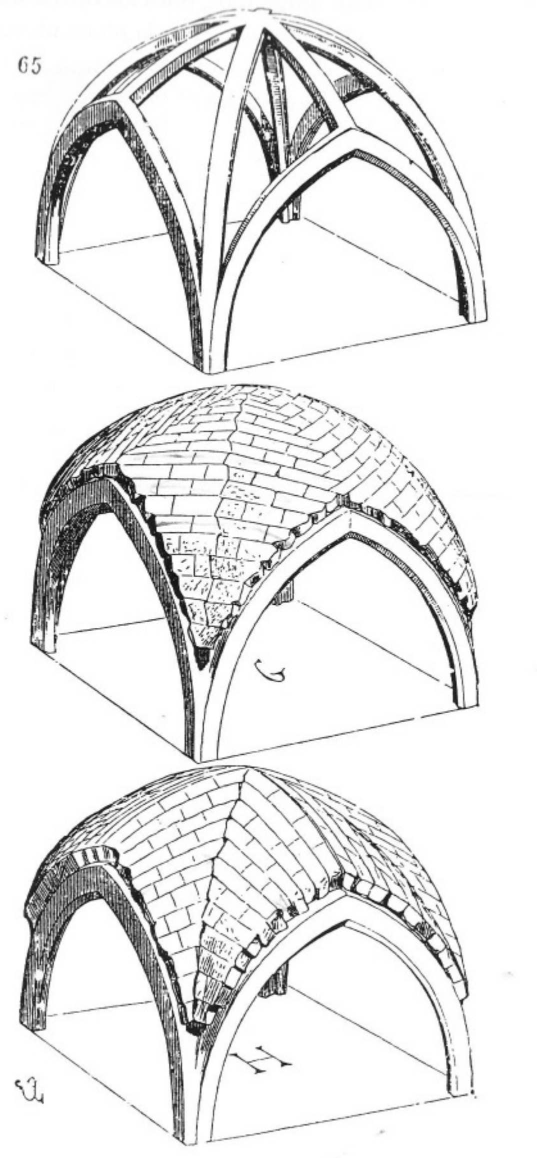


Figure. 27
Related to their different origin: from groined or domical vaults (Viollet-le-Duc 1859, fig. 64–65)

architecture on its need (Parker 1849)[33]. Just one year after Viollet-le-Duc's volume appeared Parker made his own contribution with an article in the *Bulletin Monumental* entitled "Progrès comparés de l'architecture en Angletterre et en France" (Parker, 1860). And a little bit later, in 1861, he was trying to involve both Willis and Viollet-le Duc on the debates connected with this issue, such as the case of the origin of Lincoln Cathedral.[34]

Is in this context that Viollet-le-Duc was probably forced to revise his first interpretation. In the *Gentleman Magazine* of 1861 the reviewer of the translation of the *Histoire d'un fortresse* signaled Viollet-le-Duc as the person who had pointed out the differences in vaulting in the two countries. But not plainly convinced of his explanation hoped that "our friends of Normandy will answer this question for us" (Anon 1861) In France Viollet-le-Duc theory was not unanimously accepted. In 1865 Felix de Verneilh, an eminent medievalist historian, showed his disagreement in an article in *Annales Archeologiques* devoted to compare Le style ogivale en Angleterre et en Normandie (Verneilh 1865–5, 99–100). He totally rejected the explanation of Viollet-le-Duc:"English builders didn't borrowed his vault form byzantine domes". And pointing directly against the rationalistic heuristic approach of Viollet-le-Duc he remarked that —although he had arrived to this idea "by enchaining deductions that at first sight look seem very acceptable"— was in fact wrong because these domes were "completely unknown in England and Normandy".

Viollet-le-Duc second thought on web's vaults and a belated recognition of Willis. Difference on web's vaults meant difference of technical approach

At the end, Viollet-le-Duc amended his explanation in 1868. In his article "Voûte" for the first time reckoned openly the relevance of Willis's personage "one of the most distinguished men among English archaeologist involved in architecture", and his "very vast and wisely deduced" work. He also reproduced —altering them with slight personal touches and changing of perspective— some of the Willis's drawings. At the end he couldn't help to drop some subtle criticism: Willis's was the first rigorous study on vaults, but "not having a point of comparison outside the English system the learned professor couldn't appreciate all the practical sides implicated" (Viollet-le-Duc 1868).[35]

That is, he had to come again over the question left aside by Willis: the construction and geometry of the webs. This is why he reproduced and analyzed again Willis's drawing of the Westminster vault as a starting point to discuss the origin and evolution of the peculiarities of the English solution (Viollet-le-Duc 1868, 523, fig. 34) Except that this time the explanation didn't invoke any alien origin. The solution was merely based on the "practical sides": "to simplify the

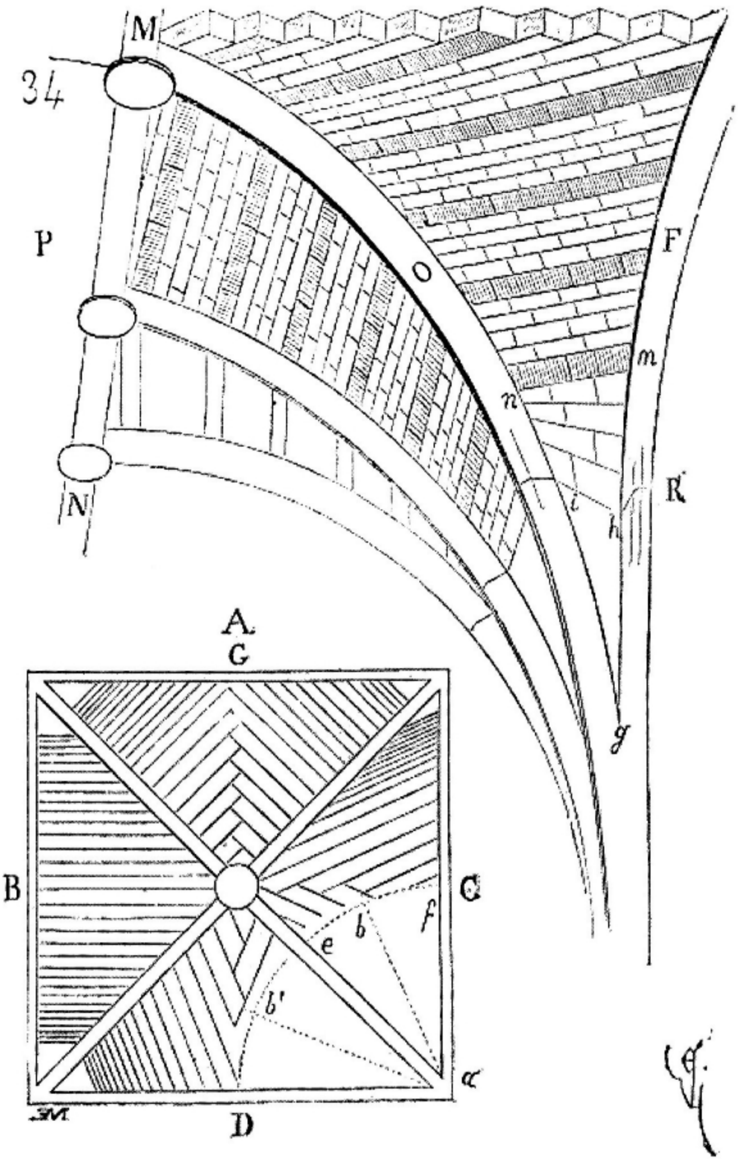


Figure 28
Viollet-le-Duc reinterpretation of Willis's drawing of the south transept of Westminster Abbey with a diagram comparing the web solution of a French vault with different English webs (Viollet-le-Duc 1868, 523, fig. 34)

work", probably inspired by wood construction: "have the English their vaults at the beginning made of stone or wood arches, covered by timber planks? (Viollet-le-Duc 1868, 524–525).

The reception by Viollet-le-Duc of Willis's "On Vaults on the Middle Ages" had in the end a paradoxical effect, on one side he amplified the impact of it, but at the same time he cast some shadows about his value. It is true he identified one weak point in this work. But Viollet-le-Duc likely failed to grasp its great merit: its heuristic approach —probably because he didn't share it—. His view was dominated by another narrative, made of focus of invention, dissemination, and progressive ingenious improvement of structural efficiency.

If the heuristic approach was different hence the role of drawing war also different. At the very beginning he probably had an eye on some of Willis drawings, picking up maybe some solutions —the wire diagrams— and narrative techniques —the toothed cut-away— and even maybe tried to surpass them, as it happened with the representation of the spandrel drawings. He also, as Willis did, used Descriptive Geometry to define virtually the form of some pieces. For both men drawing was essential: but for Viollet-le-Duc the main reason for dissecting a building was to search and demonstrate the inescapable logic of the medieval technical solution, while for Willis it consisted on the inquiry into the relationship between apparent and real construction.

Conclusion

Willis "On vaults" was a first and decisive step for building a history of gothic construction. And became a central piece for a more ambitious history. Joining this work with the previous studies on the construction of the Greeks, the prospect of a comprehensive history of construction began to take shape. As Alexandrina Buchanan has pointed out Willis's work contributed to the emergence in the 40's and 50's of a debate around both modes of construction.

It was also capital as a model of how to study a gothic construction. It indicated some fruitful heuristic approaches and forms of drawing specially adapted to them, many of them taking advantage of recent innovations and others devised by Willis himself.

Its reception in France, especially by Viollet-le-Duc had an ambiguous effect. It spread its influence, but being immersed in another heuristic approach, its real merit could pass unperceived. It risked being taken as simply as a valuable source of information —of a besides encapsulated architectural topic, English medieval vaults— than an example to be followed.

Fortunately this has not have been always the case. As we have seen at the beginning Choisy praised both its method and drawings. His was a sincere tribute.

He had been capable —for the first time in construction history— of “seeing” into the mass of the Roman vault, and understand how it was constructed. And also following Willis’s heuristic approaches: to distinguish between apparent —ribs of bricks working as arches— and actual construction –ribs used as a falsework incorporated into the concrete massif—. Discoveries, like Willis’s did, supported and expressed by superb and incisive drawings.

Notes

1. Thierry Mandoul mentioned this speech and devote d some pages to explore Willis’ influence on Choisy (Mandoul 2008, 126–130).
2. In Alexandrina Buchanan’s masterly work on Robert Willis devoted some pages to Willis’s article in a section tackling a more general issue: “the membrological Approach” (Buchanan 2013, 101–106). The most extensive study of is still found in *The Projective Cast* of Robin Evans (Evans 1999, 220–239). This author remarked that: “Willis ideas remain diffused to this day in established opinions on the development of vaults, thought Willis himself is either buried in the footnotes or raised from the dead for other reasons” (225). Also for a recent assessment see (Albuerne Rodriguez 2012).
3. Heuristic is a very rich epistemological concept. In the present contribution it designates a set of methods and approaches guiding the process of discovery.
4. See the collection of more than 200 drawings of their trip preserved in British Museum . The book eventually published in 1826 instead is lacking of interest on this matter.
5. A similar trend may be detected in France. See for example Blouet; details of Temple of Basae, (Blouet, Ravoisié 1833, vol 2: plates 17–18).
6. Inwood (1827); Stuart and Revett (1825–27) and Wilkins (1807) figure in the catalogue of Willi s’s Library (Hodgson 1874 , 33, 63, and 65).
7. J.J. Scoles encouraged from *The Builder* young people going to Greece to take advantage of “the very dilapidation of the building” as it “affords means of discovering their mode of construction which the building in a more perfect state did not disclose to a former traveler”; inviting them to draw this remains “accurately, carefully, and minutely” (Scoles 1846, 127–128).
8. “Next to complete buildings under repair, Ruins afford the most valuable information upon construction. The best instructor of all, perhaps, is a building which is being pulled down” (Willis 1842, 3).
9. “For making comparisons between one style and another, and for facilitating the rapid and correct observations of new examples… I flatter myself that the strong distinction I have drawn between the Decorative and Mechanical structures of buildings, will be found of great assistance in this respect” (Willis 1835, preface, p. v). The second chapter is labelled “On mechanical and decorative construction”. Here he said: ”Hence in all complete styles, part of the decoration is made to represent some kind of construction…this apparent frame is often different from the real one”…” It appears then, that are two things to be observed in the construction of a building: how the weights are really supported, and how the seem to be supported. The first I shall call the Mechanical, or actual construction, and the second the Decorative, or appar-

ent construction". He also warned: "The mechanical construction is no less important; and above all should be observed, the artifice by which it is concealed, and adapted to what is very often a totally different Decorative construction" (Willis 1835, 15–16).

10. In 1835 Willis: "I have said, recover the laws, because the possibility of detecting them proves that they were recognized by the artists" …"had Vitruvius been lost, we must have picked out for ourselves from a comparison of examples, just as I propose to pick out the Gothic rules" (Willis 1835, 25). In the article: "I have endeavoured throughout to show from evidence the existence and employment of geometrical methods from a very early period, and have attempted to restore some of those methods" (Willis 1842, 68).
11. "Whatever propriety of beauty a given form may possess, we find , by long continued use and multiplication, it palls upon the eye and requires change. The very characteristic by which it pleased the most, and which was nurtured and developed by every possible adjunct, will be in the next age softened down and subdued to make way for the prominence of some other, which was once in the same manner avoided or made subordinate" (Willis 1842, 66).
12. "Thus I have said nothing respecting mechanical principles, and have confined myself to form and arrangement. But it appears to me, from examination of the Works of the Middle Age architects , that the latter considerations has an infinitely greater influence upon their structures than relations of pressure , then very little understood" (Willis 1843, 46). Their respective approaches were discussed in (Mark 1977).
13. Definition de " tas-de-charge " f rom de l'Orme (Willis 1843, 5).
14. "This mass is always built of solid masonry bonded into the wall and forming part of it." From a certain determine level" the real rib and pannel construction of the vault begins, fro separate ribs are erected upon the surface of this solid"..."From below, however, if the vault be painted and decorated, this change of construction"..."is disguised or in other words, the decorative construction of the vault exhibits the rib and pannel from the abacus A upwards, but the mechanical construction is of solid masonry from A to Q, and of rib and pannel work only above this level" (Willis 1842, 7).
15. This is paragraph worth mentioning at length as it abridges the whole history of "petrification" from the spandrel to the fan vault: "Very early in the history of vaulting, the lower extremities of the panels were made solid…Next, it was found simpler and stronger to work the small portions panel surface between the branches of the boss stones out of the same block, than to cut them away and drop in the panel afterwards. Then the bosses, from the increasing complication of the patterns , began to approach so close, that it was worth while to take the pains to make them meet, and thus the Crowns and ridges of the vaults came also to be built solid. Lastly the solid construction was extended to the entire vault, and so by gradual degrees the mechanical and decorative construction of the vault , which began being identical , ended by becoming totally different" (Willis 1842, 29) .
16. Willis assumed that De l'Orme described a Gothic construction representative of a common French practice, in which "the centres of the arcs (are) upon the level of the imposts". Then he said: "This may have been the genuine French Gothic method, but in our English examples the centres are commonly place without respect to the impost level" (Willis 1842, 21–22).
17. "I think it most likely that the different forms of the middle plans which may now be observed resulted from different rues for finding the centres and raid o the ribs, which

were employed by the different schools of workmen according t o their age or nation" (Willis 1843, 16).

18. César Daly experimented with Willis 's technique of surveying, founding eventually it had its limits: for great spans it didn't work well (Daly 1843, 531).
19. Our Dilettanti Society seems to consider the "Gothic" edifices of their own country unworthy of study, or illustration; whilst they are expending thousands of pounds in publishing representations of the sculptural and architectural fragments of ancient Greece"...." "It is rather a curious fact, that some of the best engravers employed in the present work were engaged, when apprentices, in executing some of the plates for that publication: now they are matured in experience and distinguished for their skill and taste" (Britton 1819).
20. Mackenzie's drawings of King's College are in the appendix of (Tredgold 1840). Mackenzie confesses in his own separate edition that had he kn own previously "that a learned Professor, highly distinguished for his scientific investigation of the principles of Gothic Architecture… had directed his attention to the subject", he wouldn't dare to publish it (Mackenzie, 1840, preface).
21. Anyhow Willis was able to grasp that "In some examples the slope seems to be derived from the courses having been laid so as to meet the diagonal rib at right angles" but didn't go much far in its interpretation: "The perspective effect which arises from the arrangement is curious" (Willis 1842, 8).
22. For Rondelet's explanation of this plate representing a Gothic vault "similar to those of Saint-Gervais in Paris", see (Rondelet 1830–32, tome II: 55–157). This drawing calls attention also for its close resemblance with the later drawing of the vault of the corridor of the cloister of Westminster Abbey in Pugin 's *Specimens* (Pugin 1823, vol 1: plate 77 (b)) . This last one was commented by Willis, and added as illustration in Daly's translation (Daly 1843, vol.4: plate 2 figure 11).
23. Ware also devised other forms of drawing which helped to think about specific problems, such as the silhouetted vertical sections of buildings, a procedure "little used" to compare the efficiency of different buttress systems (Ware 1822, tract I: pl, 4–5).
24. On Farish and Willis, see Buchanan (2013, 59–62).
25. "Thomas Sopwith, (author of *A Treatise on isometric drawing* ,) had submitted an instrument called Isograph, which drew isometric from *drawings orthographic projection* " (Sopwith 1834, 155).
26. Corresponding to the vault of Westminster Abbey cloister (Pugin 1823, vol 1: pl ate 77); and the vault of St. Saviour in Southwark (Pugin 1823, vol 2: pl ate 47).
27. Willis's isometrics appeared also in Rondelet's *Suplemment* (Blouet, 1847, pl. IX–X) along with other illustrations on Greek construction.
28. On this Viollet-le-Duc's article, see Bressani (2014, 165–187) .
29. Martin Bressani has studied Viollet-le-Duc 's versions of the spandrel anatomy, and the reasons behind its evolution (Bressani 2013., 249–258).
30. On Willis's Canterbury and Winchester see: Buchanan (2013: 171–185) and on Willis Holy Sepulchre (Buchanan 2013: 139–149).
31. Parker published these tours in *Archaeologia, Or Miscellaneous Tracts Relating to Antiquity* between 1851–1855. Buchanan (2013, 116) pictures Parker's relationship with Willis: "If Willis and Whewell were intellectual partners in their architectural project, a similar relationship existed between Willis and Parker in practical terms".

32. Very little is known of Viollet-le-Duc's trips in England. On the relationship of Viollet-le-Duc with the country, see Middleton (1980).
33. Parker in his book on *An Introduction of the study of architecture* explored the links between French and English gothic architecture lamenting that "at present very little has been done towards a systematic comparison of the architecture of France and England" (Parker 1849, 240). He hoped the history of architecture Willis was preparing put an end to this situation (Parker 1849, 238).
34. Parker invited from *The Gentleman Magazine* both Willis and Viollet-le-Duc to debate into the English or French origin of Lincoln 's Cathedral (Parker 1861). The polemic had its origin in what Willis had said about this issue in a meeting of the Archeological Institute in 1848, and the debate was then gaining momentum. Viollet-le-Duc at least answered in 1861, denying any French origin. On the controversy on Lincoln's Cathedral, see: Buchanan (2013, 201–202).
35. But just to blame Daly for not having pointed out that Willis had not appreciated: "les différences profondes qui séparent la structure des voûtes anglaises de celle des voûtes françaises, et ne semble pas avoir étudié ces dernières". Although he conceded that "in 1843 personne n 'était en état de se livrer à un travail critique sur cet objet " (Viollet-le-Duc 1868, 550, note 23).

Reference list

Albuerne Rodríguez, Alejandra. 2012. Introducción: Robert Willis y las bóvedas góticas inglesas. In *Robert Willis, La construcción de las bóvedas en la Edad Media*. Santiago Huerta (ed.) Madrid: Instituto Juan de Herrera. xv–xxxvii.

Anon. 1842. *The Surveyor, engineer and architect for the year 1842*. London, WM.S. Orr and Co., 175–177.

Anon. 1861. *The Gentleman* Magazine. *review by Sylvanus Urban new series. X. London: John Henry Parker and James Parker*. 551–552.

Blouet, André (ed.) and Ravoisié, Aimable (ed.) 1831–1838. *Expédition scientifique de Morée, ordonnée par le gouvernement français. Architecture, sculptures, inscriptions et vues du Péloponèse, des Cyclades et de l'Attique.* 3 vol. Paris: Firmin Didot.

Blouet, André. 1847. *Jean Baptiste Rondelet. Traité théorique et pratique de l'art de bâtir. Supplément*. Paris: Firmin Didot Frères.

Bressani, Martin. 2014. *Architecture and the historical Imagination: Eugène-Emmanuel Viollet-le-Duc 1814–1879*. Surrey and Burlington: Ashgate.

Britton, John, 1819. *The History and Antiquities of the Cathedral Church of Worcester*. London: Longman, Hurst, Rees et al.

Buchanan, Alexandrina. 2013. *Robert Willis (1800–1875) and the Foundation of Architectural History*. Woodbridge/Rochester: Boydell Press and Cambridge University Press.

Butler, J. Williams. 1842. *Practical Geodesy: Comprising Chain Surveying and the use of Surveying Instruments*. London: John W. Parker.

Choisy, Auguste. 1873. *L'Art de Bâtir chez les Romains*. Paris : Ducher et Cie.

Choisy, Auguste, 1904. The Royal Gold Medal. Presentation to M. Auguste Choisy (Hon. Corr.M.) 20th June 1904. *Journal of the Royal Institute of British Architects. Vol. XI, third series,* n. 16, June 25, 1904: 452.

Cockerell, Charles Robert; Kinnard, William; Donaldson, Thomas Leverton, Jenkins, William; Railton, William,. 1830. *The Antiquities of Athens and other places in Greec, Sicily, etc., supplementary to the Antiquities of Athens by James Stuart F.R.S. and F.S.A. Nicholas Revett*. London: Preistley and Weale.

Cunningham, Alexander. 1868. *Notes on the History, methods and technological importance of Descriptive Geometry.* Edinburgh: Edmonston and Douglas.

Daly, César. Mémoire de M. Willis sur la construction des vôutes du Moyen Âge. *Revue générale de l'architecture et des travaux publics*. Vol IV, 1843, col 3–14, 289–304, 481–507, plates 16, 18 and 20.

De l'Orme, Philibert. 1568. *Le premier tome de l'architecture.* Paris: Morel

De l'Orme, Philibert, 1578. *Nouvelles inventions pou bien bastir et à petit fraiz*. Paris: Morel

Dérand, François. 1643. *L'architecture des voûtes ou l'art de traits et coupe des voûtes*. Paris: Sébastien Cramosy.

Dobson, Edward. 1849. *A rudimentary treatise on masonry and stone*-cutting. London: John Weale.

Dodwell, Edward. 1819. *A classical and topographical tour through Greece, during the years 1801, 1805, and 1806.* Vol 1. London.

Evans, Robin. 1995. *The Projective Cast. Architecture and its Three Geometries*. Cambridge Massachusetts and London: MIT Press

Farish, William. 1822. On Isometrical Perspective. *Transaction of the Cambridge Philosophical Society.* I : 1–19.

Frezier, A.F. 1739. *La théorie et la pratique de la coupe de pierres et des bois*. Paris: Jombert. Vol. 3.

Garinger Hall, Thomas. 1841.*The elements of Descriptive Geometry*. London: John W. Parker.

Hodgson. 1872.*A catalogue of the Valuable and Extensive Library of the Rev. Robert Willis, Sold by Messrs. Hogdson, April, 3 to 12, 1872*. London.

Inwood, Henry William. 1831. *The Erechtheion at Athens. Fragments of Athenian architecture and a few remains in Attica, Megara end Epirus*. London: John Williams.

Jones, E.T . 1849. *A Descriptive Account of the Literary Works of John Britton (from 1800 to 1849)*. London: C. Whiting

Lawrence, Snezana. 2003. History of Descriptive Geometry in England. *Proceedings of the first International Congress on History of Construction*. Madrid , 20th to 24th January 2003.Madrid. Madrid: Instituto Juan de Herrera. 3: 1281–1269.

Leroy, Charles François Antoine. 1834. *Géometrie Descriptive*. 2 vol. Paris: Carilian-Goeuri, Anselin.

Loudon, John Claudius. 1838. *The suburban gardener and villa companion*. London: The author.

Loudon, John Claudius. 1834. *The architectural Magazine*. Vol 1. London: Longman, Rees, Orme, Brown, Green &Longman. 369–370

Mackenzie, Frederick. 1840. *Observations on the Construction of the Roof of the King's College Chapel, Cambridge.* London: John Weale,

Mandoul, Thierry. 2008. *Entre Raison et Utopie. L'Histoire de l'Architecture d'Auguste Choisy*. Wavre: Mardaga.

Mark, Robert. 1977. Robert Willis, Viollet-le-Duc and the Structural Approach to Gothic Architecture. *Architecture* 7: 52–64.

Middleton, Robert. 1980. Viollet-le-Duc: son influence en Angleterre. *Actes du colloque international Viollet-le-Duc*. Paris: Nouvelles Éditions Latines. 274–275.

Nicholson, Peter. 1837. *A treatise on projection*. London: Groombridge.

Parker, John Henry. 1849. *An Introduction to the Study of Gothic Architecture*. Oxford and London: John Henry Parker.

Parker, John Henry. 1860. Progrès compares de l'architecture en Angleterre et en France. *Bulletin Monumental*. 464–484.

Parker, John Henry. 1860. Correspondence of Sylvanus Urban:"The Architecture of Lincoln Cathedral". *The Gentleman Magazi*ne. Vol. 210 : 3.

Poldo d' Albenas, Jean. 1557. *Discours historical de l'antique et illustre cité de Nismes*. Lyon: Guillaume Rouillé.

Pugin, Willis Augustus. 1823. *Specimens of Gothic Architecture, selected from various ancient edifices in England*.2nd ed. 2 vol. London: Taylor

Puissant, 1779. *Traité de Topographie, d'Arpentage et de Nivellement.* Paris: Courcier.

La Rue, Jean-Baptiste. 1728. *Traité de la coupe de pierres*. Paris: Imprimerie Royale.

Rondelet, Jean-Baptiste.1830–32. *Traité théorique et pratique de l'art de bâtir*. Tome 6, planches. Paris: Rondelet fis.

Scoles. J.J: 1846. On certain peculiarities in the design and Construction of the Parthenon. *The Builder*. vol 4. March 14: 127–128.

Society of Dilettanti (editors). 1833. *The unedited antiquities of Attica: comprising the architectural remains of Eleusis, Rhamnus, Sunium , and Thoricus*. 2 nd ed.London: Priestley and Weale.

Sopwith, Thomas. 1834. *A Treatise in Isometrical Drawing*. London: John Weale.

Sopwith, Thomas. 1839. Description of Instruments to Facilitate the Drawing of Objects in Isometrical Projection. In *Report of the eighth meeting of the British Association for the Advancement of Science*. vol VII: 155. London: John Murray.

Tredgold, Thomas. 1840. *Elementary principles of carpentry, 3 ed. Corrected and considerably enlarged, with an appendix containing specimens of various, ancient and modern roofs by Peter Barlow*. London: John Weale.

Verneilh, Felix de. 1864–1865. Le style ogivale en Angleterre et en Normandie. *Annales Archéologiques*, 24: 226–237; 25: 5–44; 85–102.

Viollet-le-Duc, Eugène. 1844–1847. De la construction des édifices religieux en France depuis le commencement du christianisme jusqu'au XVIe siècle. *Annales archéologiques*, 1844, 1: 179–186; 1845, 2: 75–85; 1845, 3: 321–336; 1846, 4: 266–283; 1847, 6: 194–205 and 247–255.

Viollet-le-Duc, Eugène. 1859. Construction*. In Dictionnaire Raisonné de l'architecture française du XIe au XVIe siècle*. 1854–1868. Paris: B. Bance and A. Morel et Cie. T.4, 1–278.

Viollet-le-Duc. 1861. Correspondence of Sylvanus Urban: Lincoln Cathedral. *The Gentleman Magazine and Historical review by Sylvanus Urban new series. X. London: John Henry Parker and James Parker*. 551–2.

Viollet-le-Duc, Eugène. 1868. Voûte. In *Dictionnaire Raisonné de l'architecture française du XIe au XVIe siècle 1854–1868*. Paris: B. Bance and A. Morel et Cie. T.9: 465–549.

Wilkins, William. 1807. *The Antiquities of Magna Graecia*. Cambridge: Richard Watts.

Ware, Samuel. 1814. Observations on Vaults, and the Origin of the Principal Features of Decorative Architecture. *Archaeologia* 17: 40–80.

Ware, Samuel. 1822. *Tracts on Vaults and Bridges. Containing Observations on the Various Forms of Vaults*. London: Thomas and William Boone.

Wilkins, William. 1837.*Prolusione Architectonicae; Or essays on subjects connected with Grecian and Roman Architecture.* London: John Weale.

Willis, Robert. CUL, MS. Add. 5135. Robert Willis Papers: "general preparatory works".

Willis, Robert. CUL, MS. ADD. 5138. Robert Willis Papers.

Willis, Robert. 1835. *Remarks on the Architecture of the Middle Ages, Especially of Italy*. Cambridge: Pitt Press.

Willis, Robert.1841. *Principles of Mechanism*. London: John W. Parker.Cambridge: J.& J.J: Deighton

Willis, Robert. 1842. On the Construction of the Vaults of the Middle Ages. *Transactions of the Royal Institute of British Architects* 1: 1–69.(Reprinted in a separate publication London: 1910.)

Willis, Robert. 1845. *The Architectural History of Canterbury Cathedral*. London: Longman, W. Pickering and G. Bell; Oxford: Parker; Cambridge: Deighton.

Willis, Robert. 1845. The Architectural History of Winchester Cathedral. *In Archeological Institute, Proceedings at the Annual Meeting of the Archaelological Institute…at Winchester.* September, London.

Willis, Robert. 1849. *The Architectural History of the Holy Sepulchre at Jerusalem*. London: John W. Parker; Cambridge: John Deighton.

Willis, Robert. 2012. *La construcción de las bóvedas en la Edad Media*. Ed. By S. Huerta. Madrid: Instituto Juan de Herrera.

Willis's investigations into medieval vaults: a digital re-presentation

Nicholas Webb

In 1841 Robert Willis; Jacksonian Professor at the University of Cambridge, mechanical engineer and future holder of the Royal Gold Medal for architecture, delivered his address to the Royal Institute of British Architects discussing the design and construction of medieval vaults, which was published the following year (Willis 1842). Here Willis set out hypotheses such as the relationship of vault rib arcs to their radii and apex heights, as well as the rib arc centre point's relationship to its impost line. His address was based on the principle that medieval vault construction was formed using a tracing floor plan in relation to a system of projections up and down to create the full geometry of vault ribs, rather than using stereometry as seen in neo-gothic design and construction. Alongside his text descriptions, Willis used architectural representation techniques such as orthographic plans, sections and isometric drawings, as well as sketch perspectives. Whilst these serve their purpose, relating the text to the images can often be difficult based on the complexity of the topic in question, particularly for those with little or no knowledge of medieval vaults. Therefore, the aim here is to digitally re-present the figures used by Willis to make them more accessible to all, and also demonstrate up-to-date techniques that are being used to investigate the work of Willis further as part of a larger research project.

At the University of Liverpool a small team of researchers are investigating medieval vault design and construction in the British Isles, which is inspired by the work of Willis and provides accurate documentation to further research his hypotheses (Webb and Buchanan 2016). The project uses digital techniques such as laser scanning and photogrammetry to acquire precise digital models of medi-

eval vaults, including some of those discussed by Willis, for example Exeter Cathedral and Wells Cathedral. Three-dimensional digital modelling forms a key part of the analysis process, and, as a pre-requisite to ascertain research questions for the project, it became clear that in attempting to understand the words and images that Willis uses that a digital re-presentation of his original publication had the potential to make them richer in terms of content and clearer in terms of the reader or viewer's understanding of the topic. This paper should be seen as a position piece that will explore the development of representation techniques throughout history and how these can influence our understanding of works of architecture. A visual re-appraisal of samples from Willis's publication investigating vault design and construction will then be given through the use of digital techniques.

Willis and the development of representation techniques

Mediating tools in architecture are not new; links between drawing and construction can be traced back to the Near and Far East, Mesopotamia, Ancient Egypt and Greece. Throughout history architects, master builders and scholars have made use of devices that represent buildings, primarily to enable their construction, rather than being the literal "maker" of the buildings themselves (Pérez-Goméz and Pelletier 2000). A significant example of this can be seen in Haselberger's discovery of architectural drawings scribed into the stonework of the ruins at the Temple of Apollo in Didyma, Turkey (Hadingham 2008). However, there is little evidence elsewhere to support the widespread use of scale drawings, although as we will see, representation tools were still used. In terms of pre-Renaissance representation such as the medieval period, master masons would have predominantly designed mentally and communicated their ideas verbally or using full scale drawings and models. In this way, medieval masons would have been like their ancient counterparts as they were directly in charge of, and worked directly in, the spaces they were designing. Evidence such as the tracing floor above the north porch at Wells Cathedral supports the use of full-scale drawings, where building elements were drawn on a prepared plaster screen floor and then translated into the final building constructions.

After the widespread introduction of paper, architects and designers could experiment with ideas rapidly and communicate them more effectively with others, resulting in increased dialogue and critique, using techniques such as perspective sketches to visualise design ideas. However, Renaissance theorists such as Alberti believed that orthogonal drawings were most appropriate for architectural representation, not perspective images, as they enabled a more objective communication of design ideas. Alberti stated this was because orthogonal drawings allow

measurements to be taken, enabling translation of them for construction or analysis purposes (Ackerman 2002). This demonstrates a shift towards drawing to scale rather than drawing at full scale or 1:1, with the role of mediating techniques becoming increasingly important. However, the reality was that most Renaissance architects did use perspective images to convey their ideas and this became the dominant technique in the discipline that would not be significantly challenged until the nineteenth century with the introduction of axonometric and isometric drawings.

Axonometric drawings in Europe were introduced, as is often the case with technological advances, because of their potential use in military operations. They offered geometric qualities in which correct measurements could be taken, offering accuracy in all three axes for construction purposes (Ackerman 2002). Additionally, their use as an analytical tool via calculus and geometry "made it possible to see graphic data not as a more or less approximation of sight, but as a way of calculating and predicting abstract qualities or behaviours" (Allen 2009, 14). This highlights the use of axonometric drawings beyond their visual qualities and suggests their advantages in analysis and critique of designs. However, isometric drawings, a form of three-dimensional drawing represented orthographically on a two-dimensional page, also existed in the early nineteenth century. Isometric drawings work by constructing a base line with two 30° angles, rather than two 45° angles as with axonometric drawings, and then projecting heights vertically. This foreshortens the angles projected in comparison to the standard axonometric and consequently can be easier to read, particularly for a layperson. This was one of the main representation techniques used by Willis in his study of medieval vaults, for example in his drawing of the vault of Henry the Seventh's Chapel, Westminster, which demonstrates some details of the vaults from below, but most importantly shows us the vault's construction from the roof space as well. The inventor of isometric drawings in 1822 was William Farish, who also happened to be Willis's predecessor as Jacksonian Professor at the University of Cambridge. Farish invented isometry in response to the pressing need to represent mechanical drawings objectively due to the emergence of technologies in the Industrial Revolution; he understood that perspective images distorted the true geometry of objects (Krikke 2000). Evidence indicates that Willis attended Farish's lectures, as sketches and notes recorded by Willis from them still survive (Buchanan 2013, 35). As a graduate of Cambridge and subsequently an academic there, this gives evidence to Willis's use of isometric drawings under the influence of Farish. Willis showed creativity in developing designs for drawing tools, for example the "cymagraph" which was used for tracing mouldings of vault ribs. This had a stylus which was mounted on a carriage holding a pencil that simultaneously traced the profile of the moulding contours (Bu-

chanan 2013, 60). Here we have evidence of Willis using the most up-to-date techniques, as well as further developing them himself in search of a clearer and more objective understanding of the subjects in question.

Beyond the work of Willis and Farish using isometric drawings, we see the increased significance of axonometric drawings in the research of Auguste Choisy in the 1870s. Similarly to Willis, Choisy adopted axonometric drawings as a way of visually describing the history of medieval and ancient architecture (Ackerman 2002). He believed they could "demonstrate what he assumed to be the deterministic principles according to which the great buildings of history were achieved" (Pérez-Goméz and Pelletier 2000, 314). Choisy's work is a therefore another key example in demonstrating how representation techniques can be used to augment our understanding of historic architecture; revealing a more objective truth. The use of such drawings meant that unseen features could be seen, such as worms-eye views from the underside of a building or structure; effectively explaining design elements such as wall construction.

Digital representation techniques

In his 1842 publication, Willis used a combination of orthographic plans, sections, elevations and isometric drawings, in addition to perspective sketches. Additionally, we have evidence of Willis using physical models in his lectures to further communicate his ideas (Buchanan 2013, 158). As noted previously, we see that Willis employed contemporary architectural representation techniques to disseminate his hypotheses on medieval vault construction, and was also seeking to improve his survey methods through the invention of machines such as the "cymagraph". Moving forward to the 21st century, we can confidently assume therefore, that Willis would have similarly used made use of the most up-to-date technologies if he was researching today. For both surveying and dissemination today, this can be seen in the form of computer aided architectural techniques. The widespread introduction of the computer since the late 1980s has rapidly changed the architectural profession, and by the start of the 21st century visual imagery created using three-dimensional digital software had become extensive due to fast paced developments in computing. Kalay (2004) stated that computer aided architectural techniques have shook "…the foundations of the profession as no other invention has done before".

In a research context, we increasingly see how digital techniques can be utilised. Examples using digital representation tools in historic architecture and archaeology began to emerge in the mid-1990s, with publications such as "Virtual Archaeology" (Forte and Siliotti 1997) and "Rendering Real and Imagined Buildings" (Novitski 1998) focussing on the use digital modelling as a visualisa-

tion tool. Moving forwards, the use of digital tools became increasingly complex with emphasis moving towards analysis of architecture in addition to representation. This can be seen, for example, in the work of Jane and Mark Burry (2006) where 3D digital modelling was used to explore and understand the complex geometries created by Gaudi at the Sagrada Familia church in Barcelona, enabling the building's continuing construction. Another example is the project to digitally reconstruct and analyse destroyed German synagogues by Martens and Peter (2002). The use of digital techniques to accurately survey historic works of architecture is highlighted by Richens and Herdt (2009), who identified that hand drawings of ancient ionic columns had previously been drawn incorrectly, and subsequent digital representations offered a more objective basis for analysis purposes, and an opportunity for dissemination of information. The following sections discuss how similar digital tools have been explored to re-present Willis's original figures, and the potential benefits these have in terms of enhancing our understanding of them.

Re-presentation of Willis's original *FIG.3.*

The first and simplest method chosen to enhance Willis's original figures was to overlay them with additional information. For this Willis's *FIG.3.* was chosen, which is derived from a vault in the south transept of Westminster Abbey and is presented in perspective on the left hand side and in section on the right hand side of the image (see Fig. 1).

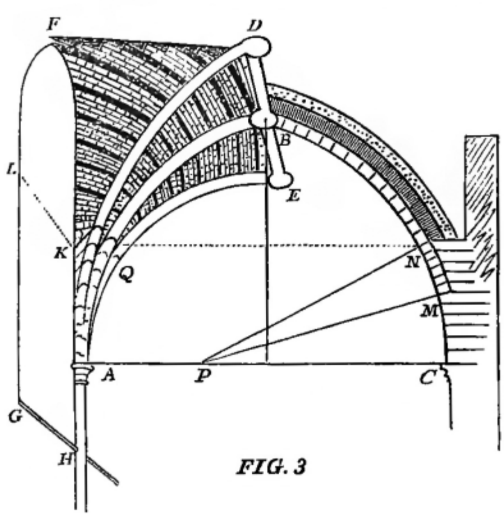


Figure 1
Willis's original *FIG.3.* that visually describes a vault derived from the south transept of Westminster Abbey (Willis 1842)

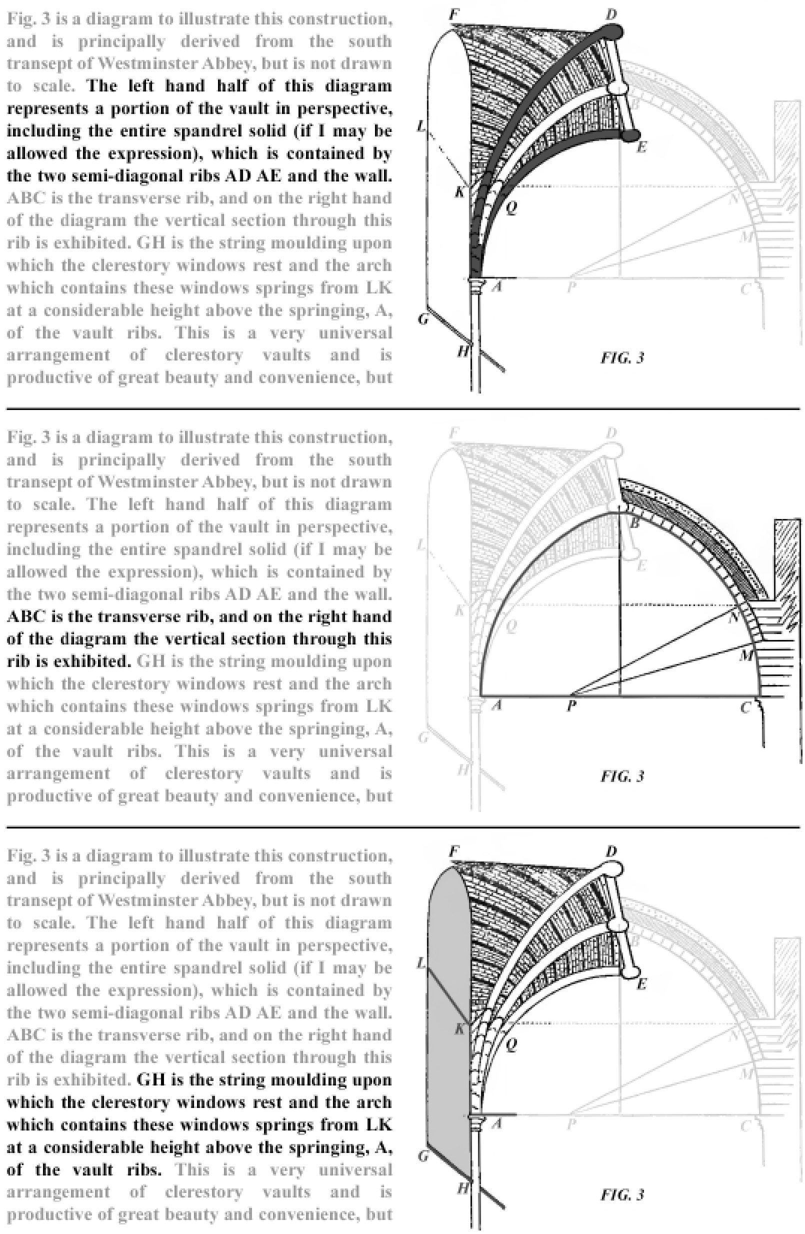


Figure 2

Mock-up of the parallax webpage re-presenting Willis's original *FIG.3.* using digital enhancements

Although the diagram successfully encompasses all elements discussed by Willis, these can at times be difficult to decipher in relation to the text due to the complexity of the topic. Therefore the first step taken was to segment the accompanying text into smaller sections discussing the different elements of the vaults, and then to pair these individual sections with a re-presented figure. The original figure was edited using Photoshop, where highlights were added in red as well as fading out areas of the figure if not discussed by Willis in that particular section. For example, the first re-presented figure was based on the text: "The left hand half of this diagram represents a portion of the vault in perspective, including the entire spandrel solid (if I may be allowed the expression), which is contained by the two semi-diagonal ribs AD AE and the wall" (Willis 1842, 4). Consequently, the ribs were highlighted in red on the left hand side of the image, and the right hand side of the image was faded out. This is demonstrated in the top image of Figure 2. To enhance this sectioning further, the accompanying images and text were presented as a parallax webpage, with the relevant text highlighted in relation to the corresponding image, and as you scroll down the page the images and text change accordingly, making the overall process easier to understand. A mock-up of the full online version of the webpage can be seen in Figure 2.

Re-presentation of Willis's original *FIG.9.*

The second method builds upon the first techniques used for the re-presentation of Willis's original *FIG.3*. Again, augmented images were paired with the relevant descriptive text, as well as adopting the same format of viewing the article as part of a parallax webpage. The main difference in this second method was, rather than using Willis's original figures and adding graphical enhancements, instead they were fully re-drawn in three dimensions as digital models. Rhinoceros 5, a solid modelling programme, was chosen for this based on its ability to create models with complex geometries, such as medieval vaults. To demonstrate this re-presentation Willis's original *FIG.9.* was used, which is a wireframe image showing an intermediate, or tierceron vault construction, in the form of an isometric drawing (see Fig. 3).

Redrawing Willis's original figure digitally was advantageous as it added graphical clarity as well as enabling additional information to be shown that is discussed by Willis but not drawn. For example, once Willis finishes discussing his basic diagram of a vault with tierceron ribs with "one tierceron between the transverse and diagonal ribs, and two between the wall rib and diagonal rib" (Willis 1842, 10), he mentions cathedrals with different tierceron arrangements such as "three and one" in the nave at Exeter cathedral and "three and two" in the nave at Norwich. Here we have shown these different arrangements in the digital

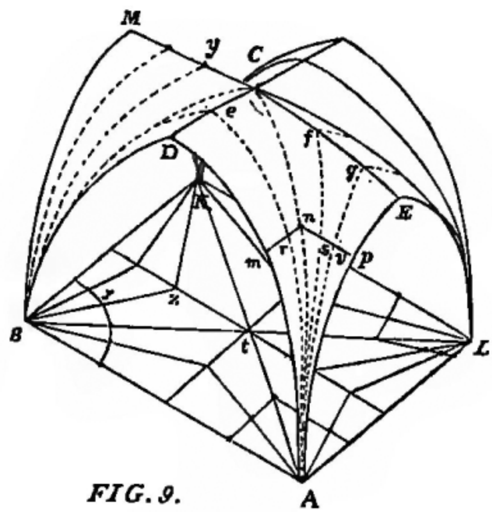


Figure 3
Willis's original *FIG.9.* illustrating a tierceron or intermediate vault (Willis 1842)

models, not only in one quarter of the bay compartment, but also across the entire bay. In addition to digitally re-presenting the basic wireframe model used by Willis, the full forms of the vaults themselves have been added, using the existing wireframe as the rib extrados lines. This offered further visual enhancement and clarity to the descriptions that Willis gives (see Fig. 4; the full parallax can be found in the webpage of the event).

Although this re-presentation aims to make clearer Willis's original figure, it still has limitations as a series of static images on a screen. Therefore, as an additional presentation, the three-dimensional model itself was also embedded into the webpage enabling rotation, zooming and exploration the model in further detail (see Fig. 5). This gives the viewer of Willis's work additional accessibility and control over what they would like to view as they can compare it to the text and explore at their own will.

Re-presentation of Willis's original *FIG.10.*

One of the more complex diagrams that Willis used can be found in his original *FIG.10.*, which combines a vault bay plan and section (see Fig. 6). The original figure and accompanying text discusses the design process required to ascertain the curvature of various ribs in a vault bay with a flat ridgeline, such as diagonal, tierceron and stilted ribs. Although the original figure contains all of the information required in relation to the text, the complexity, particularly in overlaying the

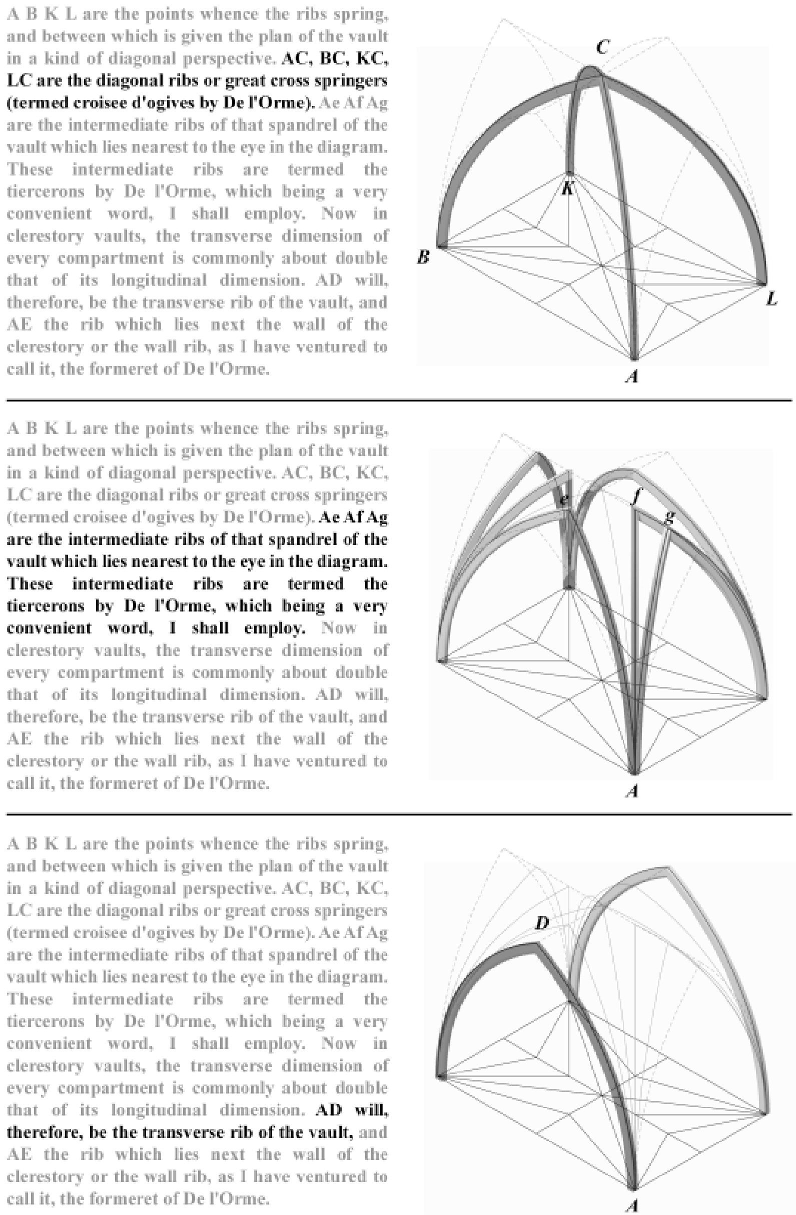


Figure 4
Mock-up of a re-presentation of Willis's original *FIG. 9.* using three-dimensional digital modelling

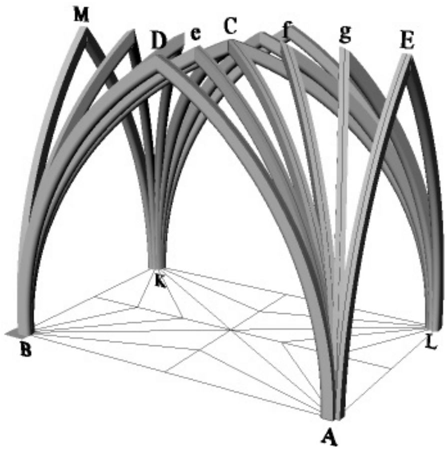


Figure 5
A screenshot of the three-dimensional digital model re-presenting Willis's original *FIG.9.*

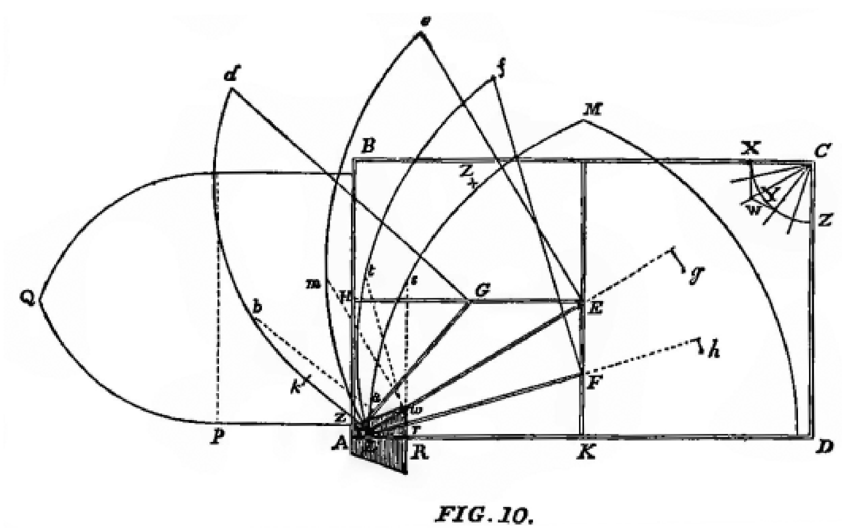


Figure 6
Willis's original *FIG.10.* illustrating a vault bay and the design process required to ascertain the various rib curvatures (Willis 1842)

plan and section together, makes interpreting the presentation challenging at times.

Therefore in the final experiment a digital animation was chosen to re-present the original figure and accompanying text, screenshots of which are shown in Figure 7, with the animation itself presented online in the webpage. SketchUp,

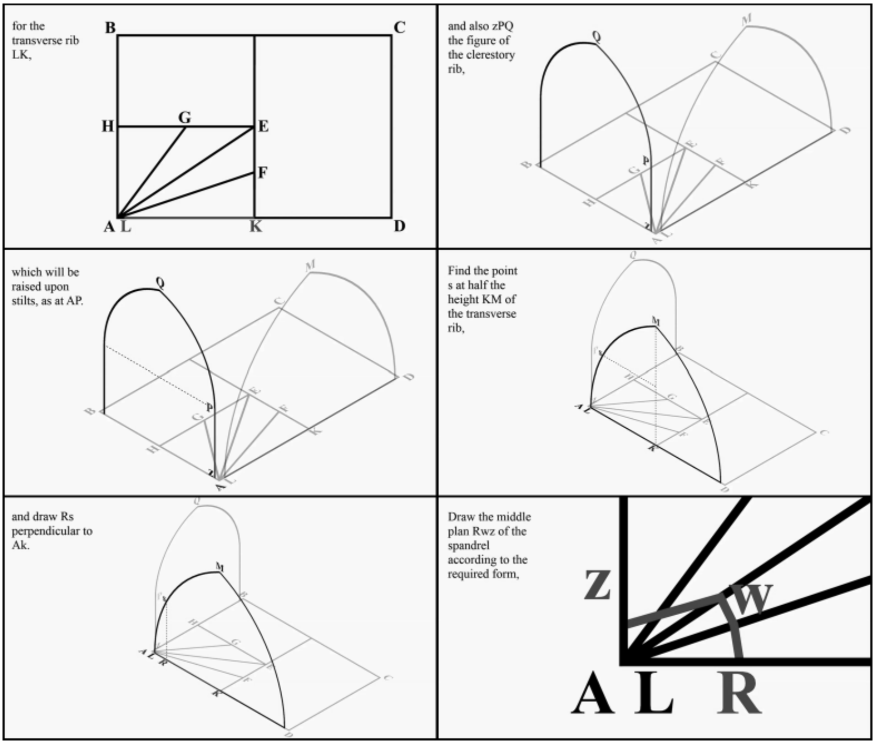


Figure 7
Screenshots from an animation digitally re-presenting Willis's original *FIG.10.*

another 3D modelling programme, was used to create a digital wireframe version of the diagram. For this the vault ribs were presented horizontally in plan as well as vertically in section, closer to the form of an actual vault, rather than overlaying them both as a flat image as seen in the original figure. Once a series of viewpoints of the three-dimensional wireframe model were created, these were exported as a video file from SketchUp to create an animation, and then the relevant sections of Willis's text were added at intervals using Windows Movie Maker. The main advantage of this method in comparison to the previous two was, as an animation, the viewer can see the transitions between the different sections discussed by Willis more clearly, allowing further exploration compared to static images. Additionally this enables the viewer to further understand the full three-dimensional geometry of the vault bay example.

Reflections and conclusions

The three re-presentations of Willis's original figures aim to enhance the viewer's understanding of his research, and consequently their understanding of medieval design and construction. The ability to deconstruct the original text and figures into a number of segmented sections makes clearer each step of the process. This is logistically possible through the use of digital techniques, specifically webpages and animations, as they enable layering of information with no concerns over space, as would be the case in a physical book or journal. Using digital tools builds on Willis's use of innovative techniques; such as presenting his hypotheses isometric and sectional drawings, rather than sketches and perspectives in most cases. Similarly, in investigating medieval vault design and construction today, we are using the most up-to-date representation techniques available to us.

Future investigations will aim to enhance the re-presentations further. The main critique of the first two methods, primarily using parallax webpages, is that they still show static images. This is first improved by adding a three-dimensional digital model to the re-presentation of Willis's original *FIG.9.*, and further enhanced in the third re-presentation using the animation. This has the benefit of showing the transition between different elements discussed by Willis; however, the viewer has less control over the speed of the presentation. Therefore the next step will be to include animations as part of the parallax webpages, and further explore the integration of three-dimensional digital models. As this paper is based on a larger investigation into medieval vault design using digital techniques, the experiments described here are vital in further considering dissemination techniques for the observations and findings acquired at sites across the British Isles such as Wells Cathedral and Exeter Cathedral.

Acknowledgements

I would like to thanks Martin Winchester for his assistance in creating the parallax webpages and Alex Buchanan for initiating the "Tracing the Past" research project.

References

Ackerman, J. S. (2002). *Origins: Representation in the visual arts*. Cambridge, MA: The MIT Press.

Allen, S. (2009). *Practice - architecture, technique and representation*. 2nd ed. New York: Routledge.

Buchanan, A. (2013). *Robert Willis (1800–1875) and the foundation of architectural history*. United Kingdom: The Boydell Press.

Burry, J. and M. Burry. (2006). *Sharing hidden power - communicating latency in digital models*, 24th eCAADe Conference Proceedings.

Forte, M. and A. Siliotti. (1997). *Virtual archaeology: RE-creating ancient worlds*. United States: Harry N. Abrams.

Hadingham, E. (2008). *Unlocking Mysteries of the Parthenon*. Available at: http://www.smithsonianmag.com/history/unlocking-mysteries-of-the-parthenon-16621015/?all (Accessed: 11 July 2016).

Kalay, Y. E. (2004). *Architecture's new media: Principles, theories, and methods of computer-aided design*. Cambridge, MA: The MIT Press.

Krikke, J. (2000). "Axonometry: A matter of perspective". *IEEE Computer Graphics and Applications* 20(4): 7–11.

Martens, B. and H. Peter. (2002). "Developing Systematics regarding virtual reconstruction of synagogues". *Proceedings of the 2002 Annual Conference of the Association for Computer Aided Design In Architecture, Pomona (California) 24–27 October 2002*: 349–356.

Novitski, B.J.J. (1998) *Rendering real and imagined buildings: The art of computer modeling from the palace of Kublai khan to Le Corbusier's villas*. United States: Rockport Publishers.

Pérez-Gómez, A. and L. Pelletier. (2000) *Architectural representation and the perspective hinge*. Cambridge, MA: The MIT Press.

Richens, P. and G. Herdt. (2009). "Modelling the ionic capital". *Proceedings of the 27th Conference on Education and Research in Computer Aided Architectural Design in Europe, 2009–09–15 – 18*. Istanbul: eCAADe, 809–816.

Webb, N. and A. Buchanan. (2016). *Tracing the past*. Available at: http://www.tracingthepast.org.uk/ (Accessed: 26 May 2016)

Willis, R. (1842). "On the Construction of the Vaults of the Middle Ages". *Transactions of the Royal Institute of British Architects* 1(2): 1–69.

Decorative versus Mechanical: A Comparative Study of Willis's and Viollet-le-Duc's Analysis of Gothic Construction

Martin Bressani
Aniel Guxholli

Two of the earliest and most authoritative nineteenth-century studies on the history of Gothic construction appeared quasi-simultaneously in the early 1840's, in England and France respectively. First, British mathematician and engineer Robert Willis's extended essay *On the Construction of the Vaults of the Middle Ages* published in the *Transactions of the Royal Institute of British Architects* in 1842.[1] Second, Eugène-Emmanuel Viollet-le-Duc's famous serial article, *De la construction des édifices religieux en France, depuis le commencement du christianisme juqu'au XVI siècle*, published in the *Annales Archeologiques* between 1844 —1847. Comparing the two studies is fascinating not only because they were produced at almost the same time and on the same topic— the emergence and evolution of Gothic vaulting in the Middle Ages —but they also both positioned themselves in the objective territory of empirical observations, avoiding the overtly speculative. The question of how Viollet-le-Duc compares to Willis is even more enticing when we consider that the former had studied closely the latter's account, as it was translated and published in France's most prominent architectural journal just the year before he set to work on his own.[2]

Many scholars in the past have assumed affinities in the approach of the two men.[3] Indeed, their analysis of Gothic construction are perfectly compatible; the one never contradicting the other. In point of fact, we know that they respected each other's work. In the second volume of his famous *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle*, Viollet-le-Duc refers directly and appreciatively to Willis's later monograph on Canterbury Cathedral (Viollet-le-Duc 1854–1868, 2: 186, 350). In 1859, Willis would re-publish an illustration

drawn from Viollet-le-Duc's *Dictionnaire raisonné* (Mark 1977, 2). They would eventually meet and establish a cordial exchange at at least two occasions: the first time in Cambridge in June 1850 when Viollet-le-Duc carried his three-week journey to England with Prosper Mérimée; the second in Paris in July 1855 when they dined together with Mérimée, the latter calling Willis "their friend" from Cambridge.[4]

Yet the compatibility between Willis and Viollet-le-Duc can be maintained only when their works are examined within a very narrow compass. When considered more broadly, we quickly get a sense of the gulf that separates their work and attitude. Willis's scientific and austere investigation of Gothic, which he describes as "a curious and interesting subject" (Willis 1842, 2), stands in sharp contrast to Viollet-le-Duc's passionate panegyric of medieval construction. Willis's antiquarian minutiae, calmly seeking to understand the precise geometrical system at the basis of the Gothic traceries is in vivid contrast to Viollet-le-Duc's use of Gothic as ammunition against the entire French academic system, summoning contemporary architects to return to Gothic to regenerate France's national architecture. Despite all his thoroughness in visiting sites, collecting direct, empirical evidence, Willis, the mathematician and Cambridge professor, studies scientifically and abstractly, from his desk; Viollet-le-Duc, the architect, speaks from the building site, directly involved in dicey restoration projects, rebuilding entire churches. Willis sometimes hints that he *may* have found some of the original methods used by medieval masons;[5] Viollet-le-Duc always feels absolutely confident that he speaks the way the old French masons thought and built.

What sets Willis and Viollet-le-Duc so much apart is not merely a difference in tone and a different set of extraneous goals; it is their vision of the architectural object itself. Let's first consider Viollet-le-Duc's account in more detail. His 1844–47 serial article traces the slow rise of the new Gothic structural system in France from the 11th to the 16th century. It tells the story of how medieval churches in France transform into Gothic through a long evolutionary process, as if a single building progressively grew into its proper shape. Seeking a new architecture, larger, more durable, and more coherent, the medieval builders of the 10th and 11th century replace the traditional carpentry roofs of their churches with a stone vault, the initial step of the long medieval building adventure. By trial and error, builders progressively develop the full potential of the vaulted space. This evolution follows distinct and complex stages, but the basic idea is simple and appears early. Wilfully leaving behind the massive concrete construction of the Romans, a technique only possible within a slave economy, French builders of the eleventh century adopt a lighter system whose strength relies entirely in the cunning assembly of smaller stones, easily handled by one worker and allowing greater tolerance to construction settlement and movement. The essential charac-

teristic of the new constructive system is a new skeletal mode of differentiated functional parts: from the simple barrel vault uniformly dressed is progressively added a series of transverse reinforcing ribs laid regularly along the nave and reinforced by a series of buttressing piers aligned with these new ribs. The barrel vault and its walls slowly transform into an infill skin stretched between a network of structural ribs:

> Already the churches of the eleventh century possess this vigorous skeleton, which, once made lighter and studied more carefully, will create the most beautiful architectonic combinations. The transverse arch, made independent of the vault, gives it nerve and strength without any added burden (Viollet-le-Duc 1844–1847, 1: 186).

It was an example of "this *elastic* mode of construction … which the thirteenth century perfected in such extraordinary fashion." (Viollet-le-Duc 1844–1847, 1: 186) Viollet-le-Duc describes the various stages whereby a skeletal structure completely liberated itself from the mass of the wall or the vault, a description expanded later in his *Dictionnaire raisonné*. There is no need to review the detail stages of that transformation here, except for emphasizing the essential idea of "liberation": a system of ribs pulls out of the mass of the vault to form an independent and elastic skeleton. Viollet-le-Duc demonstrates how the new vaulting system is extremely flexible, allowing the covering of any complex configuration of spaces as long as it could be divided into a series of triangular segments. He also stresses the ease of erection. The ribs follow a single curve and their *voussoirs* (or "*claveaux*") of similar size were easily handled by one mason. Once the ribs were erected, the infill of the vaults ("*voûtains*") could be built simply using a sliding wooden template (a "*cerce*") bearing on the outer curve or surface (the extrados) of the ribs. In short, medieval construction evolve into a flexible, simple and economical system. It reflects, according to Viollet-le-Duc, a profound historical transformation: the liberation from the authoritarian regime of Roman civilization towards the blossoming of individuality characteristic of Christianity.

Compared to this ambitious and broad history of medieval construction, Willis's *On the Construction of the Vaults of the Middle Ages* appears infinitely more modest, delving into only one aspect of Gothic construction: the geometrical system used to trace the ribs in the Gothic vault. His goal is to figure out "… what geometrical methods were really employed in setting out the work, and how the necessity for these methods gradually arose" (Willis 1842, 2). He is thus simply tracing the rise and progress of a geometrical method, an exercise in descriptive geometry.

Unlike Viollet-le-Duc, he lays no absolute claim that this method, derived from his own examination of medieval churches, are exactly the same used by

medieval masons. He is too aware that contemporary geometrical knowledge is more complex than "the rude practical geometry of the Middle Age workmen" (Willis 1842, 24). But he is confident that they carry the same "spirit" and thus prove useful in two ways: first, to help understand the principles behind medieval constructions, and second, to allow modern architects to intervene in these structures without ruining their character. Willis singles out British architect and engineer Peter Nicholson's attempts to construct Gothic vaults with cuniconoidal surfaces and other "fanciful hypothesis" laid out in his popular *Builder's and Workman's New Director* (1834) as a method that ruins the character of medieval works (Willis 1842, 22). A thorough understanding of the underlying geometrical principles used to build ancient structures and their method of application was essential to know how to design them instead of simply copying the outward form. For Willis, the knowledge of such geometrical operations was necessary not only to understand Gothic vaulting, the subject of his paper, but for works in any style of any age. Accepting the inherent eclecticism of his era, he writes: "We, imitators of all styles, must have more comprehensive and flexible rules, capable of imparting to our works the characters of every age in turn." (Willis 1842, 23–24)

So Willis investigates the development of only one specific element of Gothic construction —the vault, and in particular, its rib. Examining carefully different buildings, bringing to his discussion considerable and minute empirical evidence, he is able to recover the application of geometrical methods as a principle behind the evolution in forms. Unlike Viollet-le-Duc, the paper is not envisioned as a general history of medieval vaults, but, like Viollet-le-Duc, he does follow a historical line of progression of British medieval vaulting from the rough early Norman, when the necessity for a geometrical system first arose, through the increasing complexity of the rib framework in the *lierne* vaults, ending with the most elaborate specimens of fan vault tracery. Going up to the first quarter of the fifteenth century, Willis's inquiry extends well beyond Viollet-le-Duc's study of French medieval construction, which stopped at the 13th century. Viollet-le-Duc may have intended to go on to the 16th century, as he seems to have left his account incomplete, but we know of course that he considered post-13th century developments to represent a decline. Willis too was generally critical of the whimsical manifestations and "the fanciful rage for intricacy" of this period which he calls the "*After Gothic*." But he distinguished the flamboyance of late-Gothic in France and Germany, from the elegance and architectural fitness of the English Perpendicular.[6] For him, English fan vaults represented the highest development in the art of vaulting.

In Willis's account, advance in the construction of medieval vaults is strictly related to advance in stereotomy, in other words advance in geometrical tracing.

The rib being the first and most important constructive element that medieval masons had to resolve, Willis focuses exclusively on it, seeking to determine the method that was required to insure their adjustment in increasingly complex systems.[7] The early Norman "waggon vaults" of rubblework presented no difficulties in stone cutting, but the later introduction of ribs in groined vaults posed considerable problems: their spans and curvatures differed in the transversal, longitudinal, and diagonal directions of the compartment; from the abacus (the top of the capital of the column below), they sprang off at different angles, in different directions, and from different heights, which caused problems in arranging their entanglement and accommodating the vaulting surface above. Geometrical operations were required to manage simultaneously the curvatures in the ribbed groined vault, the shapes of the individual *voussoirs* and their close intertwining at their springing. In the subsequent evolution of British vaults, ribs increased in number and kind, to be combined in the more complex systems of the *lierne* vaults that required again more advanced methods in stereotomy to determine the exact profiles of the *voussoirs* and bosses (Fig. 1). As the number of ribs and the branching of their neighbouring boss stones increased, the infill panels between the ribs diminished in surface, until it was completely superseded by solid masonry in parts of the vault. The increasing complexity in the layout of ribs thus profoundly altered the constructive character of the vault: from a rib and infill system, where a framework of ribs supports the vaulting panels, we move to pure solid masonry with the fan vaults (Fig. 2, 3). In these late specimens, Willis explains,

> the quantity of decoration is so much increased, and its parts become so small, that it is no longer practicable to frame the tracery of these vaults on the rib and panel system with liernes and boss stones, and consequently, the portions near the crown of the vault, where the decoration is compressed and crowded, are always constructed of jointed masonry. But the branching ribs below the first series of arch heads are still built of long stones filled with panels, and the *tas de charge* from whence the ribs spring is also laid in level courses as before (Willis 1842, 44).

Even if he recognizes the different steps in the development of the art of vaulting and lays out geometrical methods pertaining to each of them, Willis's analysis falls well short of the lively narrative that animated Viollet-le-Duc's account. He never brings up broad civilizational shifts to explain transformation in vaulting. He keeps strictly to the problem at hand, which is the very abstract question of the geometric tracing of the rib. But it must be emphasized that the abstraction of his geometrical argument is not carried at the expense of empirical evidence. On the contrary, Willis is extremely specific and minute in his observa-

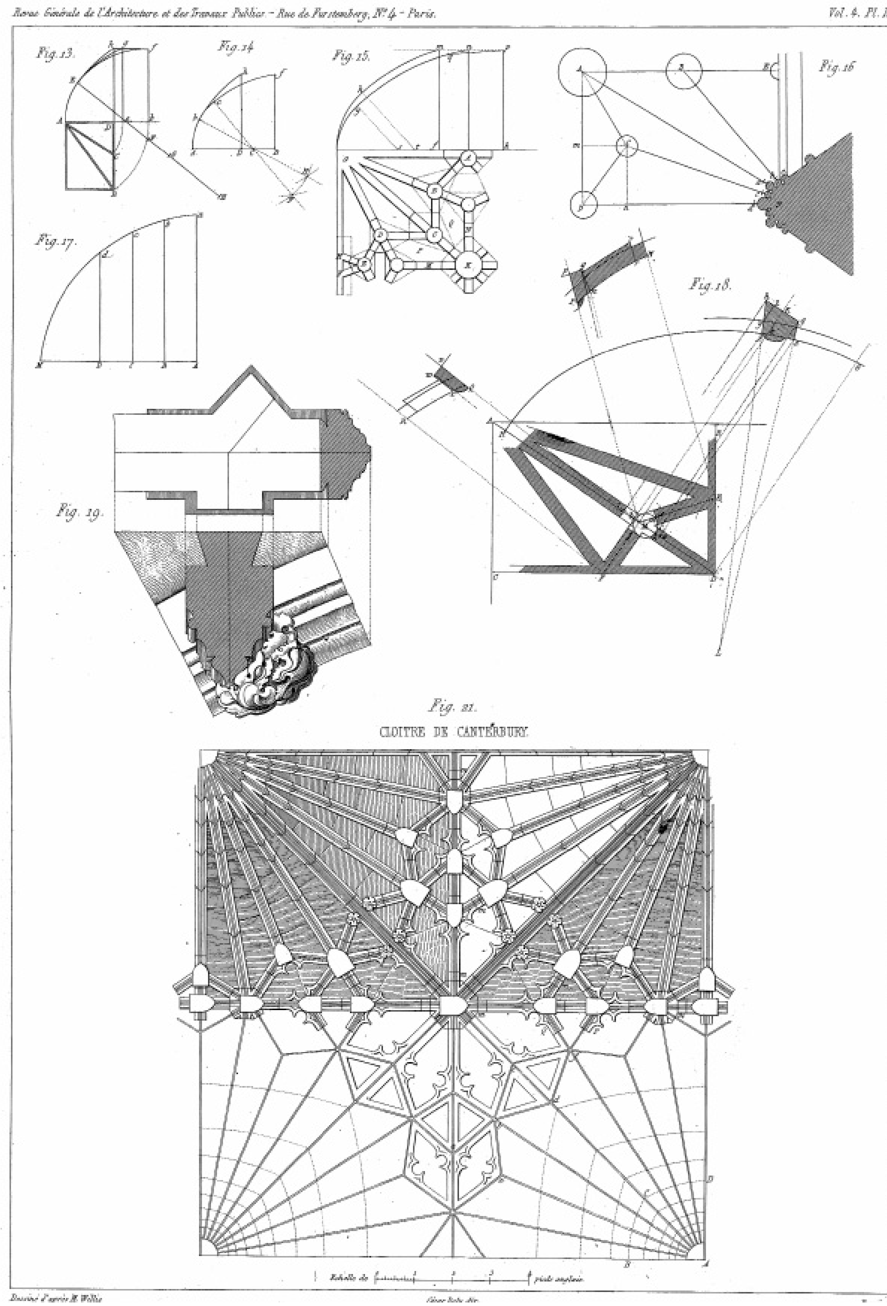


Figure 1
Willis. Geometrical methods to trace the curvature of ribs in simple vaults with *tiercerons*, and of the *voussoirs* and *bosses* in lierne vaults[8]

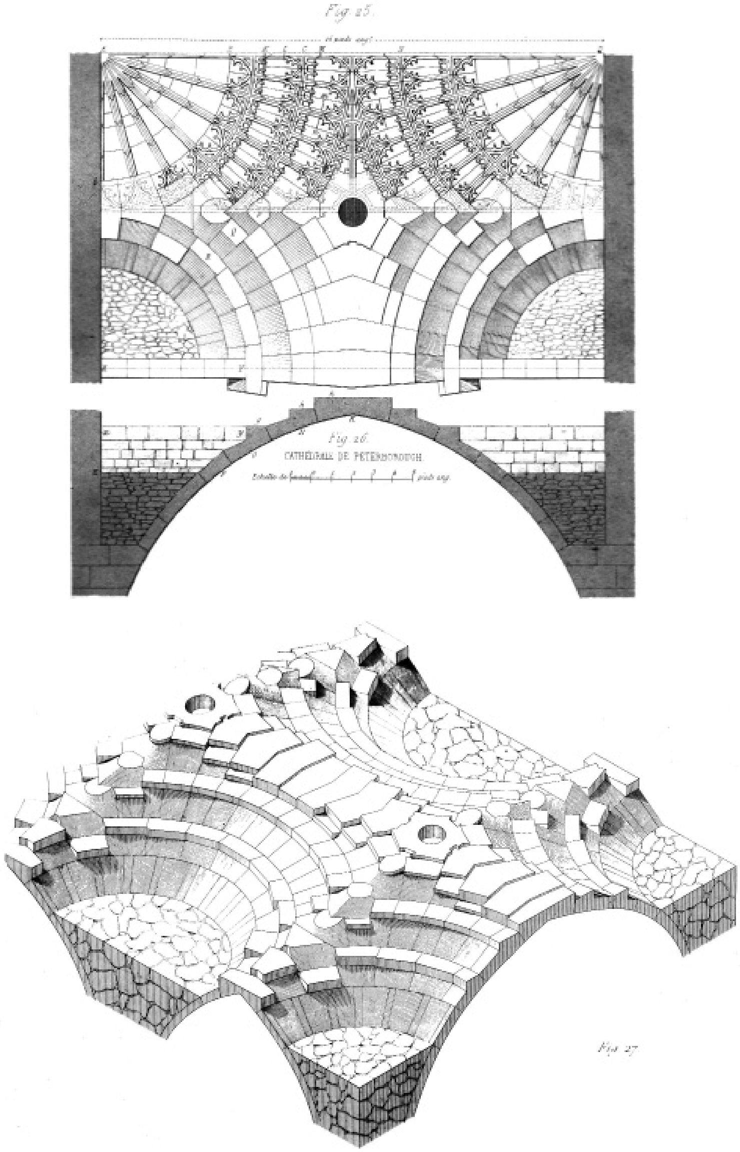


Figure 2
Willis. Fan vault covering a chapel at the east end of the Peterborough Cathedral. *Left, above*: “The upper half of the plan represents the the lower surface of the vault with the joints of the masonry and pattern of the tracery, the lower half shows the upper surface of the vault with its joints. *Left, below*: “Vertical section, showing the portion of the vault within the spandrel A B b, constructed of rib and panel work like the older vaults”. The section also shows the spandrel to be filled up with rubblework. *Right*: Isometrical projection of the upper surface[9]

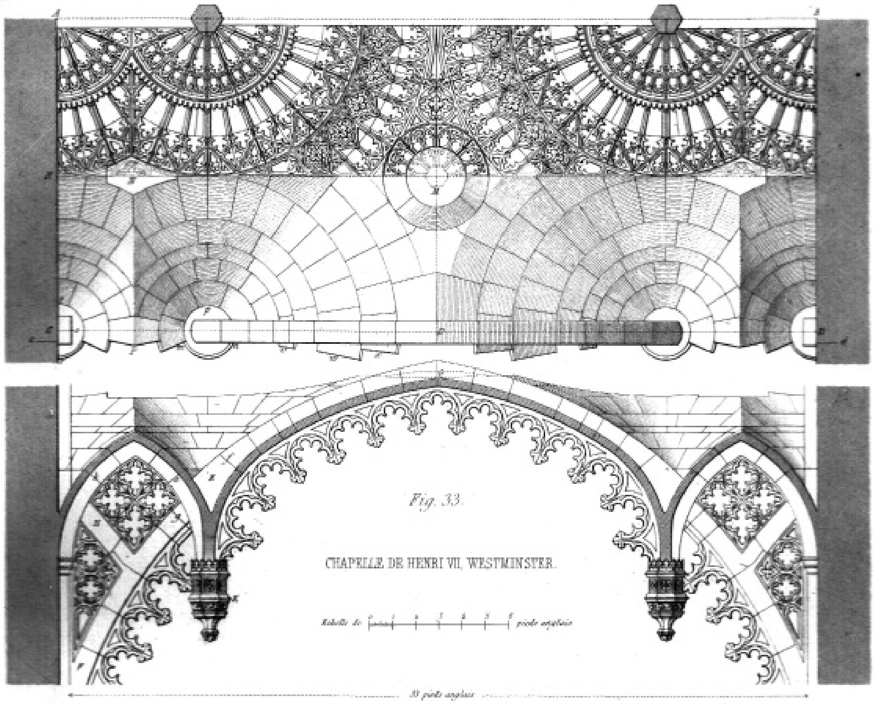


Figure 3
Willis. Vault of Henry the Seventh's Chapel at Westminster. Plans of the lower and upper surface, and section[10]

tions of actual structures. He climbed up scaffolds to look closely at existing vaults and their stone coursings, he carried precise in situ measurements, or, even better, collecting stones from recently demolished buildings, checking their beds for old mason's marks that would provide clues of the geometrical matrix used in the original building operation. In short, he follows the typical scientific method: scrupulous amassing of empirical data, which is then subjected to abstract analysis to identify general principles.

Paradoxically, Viollet-le-Duc, whose direct, empirical knowledge of Gothic buildings we must assume was vastly superior than Willis's, is much more general in his examination. He already had four years of restoration experience under his belt when he set out to write his account of Gothic construction in 1844, notably the very difficult restoration of the abbey church of Sainte-Madeleine at Vézelay, whose central nave he completely dismantled and rebuilt from the ground up. A big portion of *De la construction des édifices religieux en France* is

based upon the analysis of that church, which he knew intimately. Yet his approach is never as minutely archaeological as that of Willis. To be sure, a detail description of medieval vaulting occupies a crucial place in Viollet-le-Duc's account. He describes in detail how the 11th-century architect overcame the difficulty of vaulting compartments of unequal sides when the barrel vault was replaced with a groined vault. It was these constructive complexities that led to the use of the pointed arch and eventually to an entirely new structural conception. In Chapter V dedicated to the question of vaulting, Viollet-le-Duc discusses in detail, just like Willis, how the *voutains* (the infill between the ribs) were built and the geometry of the *tas de charge* at the springing of the ribs. But ultimately his goal is to convey "broadly" the structural behavior of Gothic churches, which he describes as an elastic structure in equilibrium. His analysis culminates in two examples that show a perfect arrangement of the ribs in a complex, perfectly equilibrated structural system: the Chapel of the Virgin at Auxerre Cathedral, and the main crossing of the Cathedral of Laon (Fig. 4). So if the ribs are a frequent subject of discussion in Viollet-le-Duc's account, they are never examined as an isolated member but are shown in relation to the larger structure of the building skeleton, and the building technique of the vault. In the example of the Virgin Chapel at Auxerre, for instance, Viollet-le-Duc shows how the springing level of the three different vault ribs over the entrance are calculated based on their curvature, which, in turn, result in an ingeniously combined equilibrated system of pressure. In other words, Viollet-le-Duc's end point is always the mechanical behavior of the entire architectural organism.

Willis, in contrast, omits mechanical considerations entirely. The geometrical procedure he seeks to uncover is devised solely to solve problems of *form and arrangement* rather than pressure. It arose as a necessity of stone-cutting, to obtain the faces of members such as the *voussoirs* in simple ribs or complex patterns, but also to govern the general relationship between the components of the vault, a geometrical relationship of mutual dependence that could be combined towards ever more complex decorative effects. Willis concludes his entire analysis with a clear statement about the priority of the decorative over the mechanical, a significant passage already quoted by Robert Mark:

> … I have said nothing respecting mechanical principles, and have confined myself to form and arrangement. But it appears to me, from [the] examination of the works of the Middle Age architects, that the latter considerations had an infinitely greater influence upon their structures than the relations of pressure, then very little understood, and about which they made manifest and sometimes fatal errors; so that this omission may be fairly allowed, or at least the discussion of this part of the subject be carried on separately (Willis 1842, 68–69).

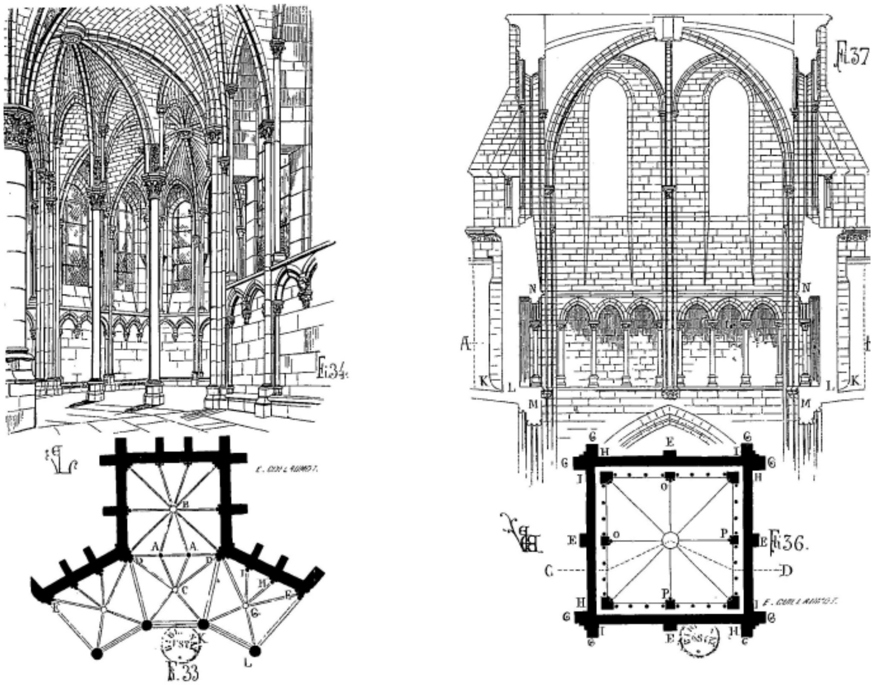


Figure 4
Viollet-le-Duc. *Left*: Auxerre Cathedral, Chapel of the Virgin, XIII century. Elevation and Plan. *Right*: Laon Cathedral, Crossing, XIII. Elevation and Plan[11]

Willis is not interested in structure, at least in his 1842 study. He was explicit in rejecting the structural interpretation of Gothic in an earlier, more ambitious publication, *Remarks on the Architecture of the Middle Ages, especially of Italy* published in 1835. In the introduction, he writes with great emphasis:

> There is a fascinating simplicity about that theory which would derive [the origin of the pointed arch] from the requirements of vaulting, that makes one wish to find it true; but I am sorry to say, that notwithstanding the favourable prepossessions with which I set out, I have been compelled to dissent from this ingenious hypothesis (Willis 1835, iii–iv).

Willis is not less rational than Viollet-le-Duc, nor more conservative, he simply speaks from a scientific standpoint. There is simply too much empirical evidence that contradict the structural interpretation. He thus concludes his introduction to the *Remarks on the Architecture of the Middle Ages* as follows:

> If this theory must be rejected, it may be asked what other is to be substituted. I do not believe that we have sufficient data to determine the question, but as so many observers in all countries are occupied in the collection and publication of examples, this deficiency is daily diminishing; in the mean time I am inclined to think the balance of evidence in favour of the Saracenic origin of these forms, all of which appear to have been used by them; and it is remarkable too, that both the trefoils and ogees are worked in the Arabian manner, on their first appearance, of which some examples appear on Plate VIII (Willis 1835, iv–v).

The passage is remarkable in showing the extent to which Willis is willing to let the decorative profile of simple trefoils or ogees provide evidence to such a complex question as the origin of Gothic. Willis is not being superficial or careless. His observation reflects a very considered position about the origin of architecture, which he sees as product of an initial process of formal imitation, which is then followed by a period of development towards greater control and coherence.

The second chapter of his *Remarks on the Architecture of the Middle Ages*, titled "On Mechanical and Decorative Construction," deploys a sustained argument about the distinction between form and construction. The first paragraph reads as follows:

> The eye, even of an unpractised observer, when viewing a magnificent building, is never satisfied, unless the weights appears to be duly supported, and it receives a corresponding pleasure when that is the case. Hence in all complete styles, part of the decoration is made to represent some kind of construction, and the more completely this is effected, the more satisfactorily becomes the result. To be sure this apparent frame is often totally different from the real one, but so long as the inconsistency is concealed, that is a matter of no consequence.
>
> It appears then, that there are two things to be observed in the construction of a building; how the weights are really supported, and how they seem to be supported.
>
> The first I shall call the *Mechanical*, or actual construction, and the second the *Decorative*, or apparent construction, and it is necessary to make a strong distinction between them (Willis 1835, 15).

To be sure, Willis is appreciative of an architecture in which the decorative construction reflects the mechanical, or the *actual* construction, but he is far from condemning architectures that do not achieve such correspondence. In fact, he describes the gap between the decorative and the mechanical as inherent, describing it as "that strange perverseness that has always prevailed in architecture" (Willis 1835, 22). There is in Willis an almost Ruskinian appreciation of

the decorative as the site of the genuine and true architectural impulse. Even when describing the greatest achievements of Northern Gothic, he acknowledges the remaining gap between decorative and mechanical construction. Here is how he summarizes the development of Gothic in his *Remarks on the Architecture of the Middle Ages*:

> In tracing architecture from these [barbaric] sources, we soon find it throwing off its barbarous characters; the arch and vault not longer trammelled by an incompatible system of decoration, but favoured by more tractable forms, are only limited by the skill of the builders, and at length a new decorative construction is matured; again, with admirable ingenuity separating itself from the mechanical construction, but not, as at first, thwarting and controlling it, but assisting and harmonizing with it; this is the complete Gothic style (Willis 1835, 20).

So even within the "complete Gothic style," the decorative construction separates itself "with admirable ingenuity" from the mechanical construction. The former may well "assist and harmonize" with the latter, a gap remains between the two. In fact, a careful reading of Willis's *The Construction of the Vaults of the Middle Ages* reveals that it is the decorative that leads the way, the mechanical adjusting to the imperative of increasingly complex traceries of the framework of ribs. For instance, Willis greatly admires the fan vaults of the 15th century, yet in this case the decorative no longer keeps any sort of relationship with the mechanical construction. He writes: "the rib and panel construction was finally driven out and superseded by solid masonry, although to all appearance the vaults continued to be formed of ribs and panels as usual." (Willis 1842, 42) Willis's famous plate of Henry VII's chapel at Westminster (Fig. 5) is also a powerful illustration of the gap between these two systems in architecture: the lower surface of the fan vault, seen from below, maintains the rib and decorative panel appearance, but its upper surface displays most plainly the entire mechanical construction, creating a "very striking and bold effect" (Willis 1842, 54).

In short, Willis's *On the Construction of the Vaults of the Middle Ages* could be re-titled as *On the Decorative Construction of the Vaults of the Middle Ages*. It is entirely focused on the problem of describing a formal system, and the method to trace that formal system. But there is absolutely no concern for the way the medieval building actually stands up and resists gravity. Robert Mark thought paradoxical that Willis, the engineer, conducting a very scientific study on medieval construction, has no interest on the extraordinary feat of engineering that are Gothic churches. But Mark may have been swayed by his own exclusive focus on structure. Willis, for his part, was a mathematician as well as an engineer, so the problem of descriptive geometry was in itself a worthwhile

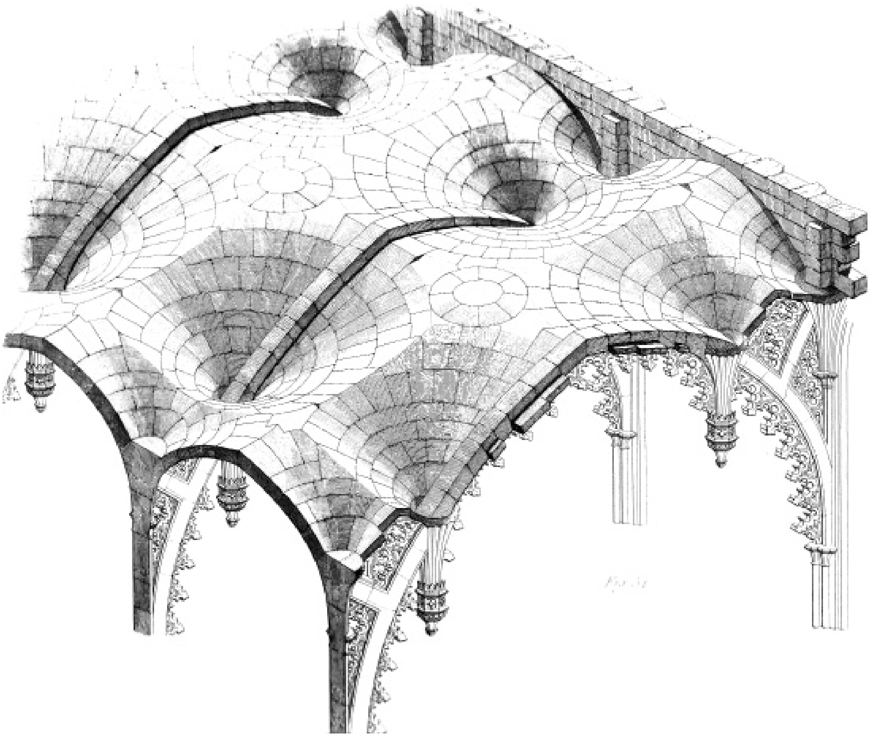


Figura 5
Willis. Isometrical drawing of the Vault of Henry the Seventh's Chapel at Westminster. The rib and panel method is entirely abandoned in this vault, which is constructed of jointed masonry[12]

scientific object. And we must recall that it was empirical evidence itself that led him away from a structural interpretation: the Gothic framework of ribs was a system into itself, following its own logic, apart from immediate mechanical necessities. Architecture's "strange perverseness" thus allows a breathing space between decorative and mechanical construction. For Willis, we may assume, it is within that gap that the builder's imagination was able to deploy itself more freely.

Viollet-le-Duc, needless to say, holds a different position. No gap should remain between the visual and the structural—or at least one should never be carried autonomously from the other. The Gothic cathedral may be richly ornamented, but it is a decorated construction, not the construction of decoration as Willis would have it. The priority shifted.

The reader should not be misled: Viollet-le-Duc is not a narrow positivist that wants appearance and reality to match perfectly; nor does he wish to put any restraints on the decorative impulse. On that latter issue, it is interesting to look ahead at his later career and turn to the famous drawing of a table appearing at the end of his *Histoire d'un dessinateur,* a woodcut drawn just before his death (Fig. 6). That isolated drawing has often been used as eloquent evidence of Viollet-le-Duc's structural rationalism. But it shouldn't be seen in isolation from the figure that comes next within the novella (Fig. 7): the completed, decorated version. From the rationality of a simple wooden assembly we move to a flamboyant flow of energy. Such flow emerges out of the table as a rationally constructed wooden framework; it forms the proper expression of the loads it bears and the function it fulfils. The decoration may be in excess of the table as a rational piece of carpentry, but it is not its contradiction. It is indeed the true embodiment of the labour, will and passion that went into making it.

The same can be said of Viollet-le-Duc's first essay *De la construction des édifices religieux en France.* He is documenting the constructive process whereby the medieval church transformed from a simple stone nave with a barrel vault into a complex but lighter skeleton held in equilibrium thanks to a system of flying buttresses. (Figs. 8, 9). In contrast to Willis, who seeks above all an archaeological truth, Viollet-le-Duc wants to untangle the "true story" hidden behind the archaeological records: he wants to restitute a national history. The leading plot of his narrative is structural: the story of the emancipation of a skeleton from its original stone mass. The reader is presented with one single historical adventure whose thread, in the most natural of fashion, leads to the final resolution of the problem of vaulting a church while allowing maximum space and light. From the old basilica church to the fully formed Gothic cathedral, it is one continuous search. The exhaustive and often tedious geometrical demonstrations of Willis give way to a series of chronologized construction *events* that are tied to one another by the force of a teleological development. It is highly significant that much of his narrative relies on the example of Sainte-Madeleine at Vézelay, the church that he himself was in the process of restoring. There is a quasi-mythic coincidence between Vézelay in 1844, the site of Viollet-le-Duc's own initiation to the arcanes of Gothic construction, and Vézelay in the Middle Ages, the birthplace of the Gothic, according to Viollet-le-Duc. The story of the progressive growth of Gothic in the Middle Ages published in the *Annales archéologiques* is nothing less than a repetition of his own action at Vézelay —the chief goal of his rather forceful repairs at Sainte-Madeleine being to clarify and illustrate the transition between the first experiments in vaulted construction of the 11th century and its final resolution in the fully developed 13th-century Gothic (Fig. 10).

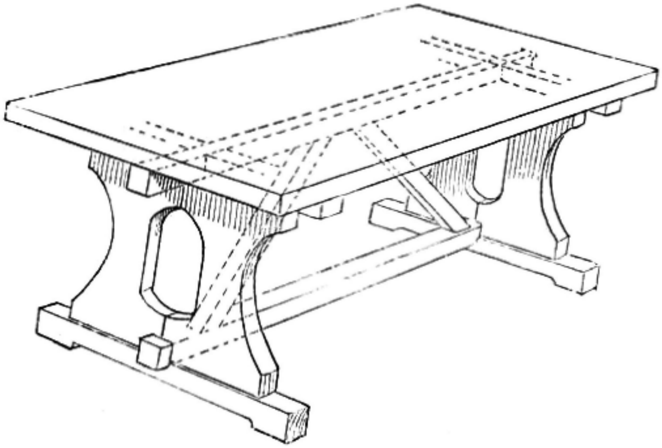


Figure 6
Viollet-le-Duc. Composition: a table[13]

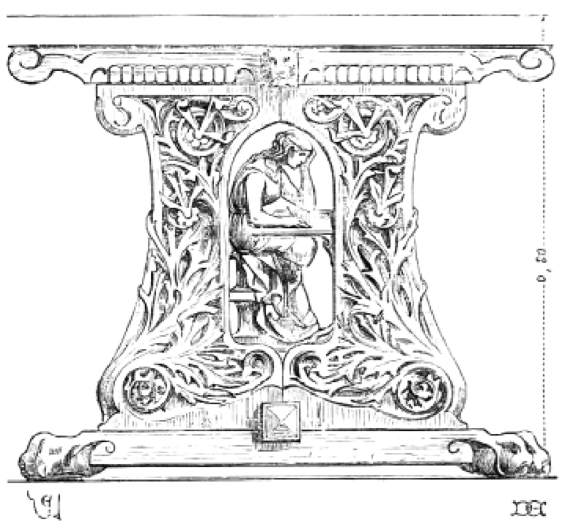


Fig. 7
Viollet-le-Duc. Decorated detail of the table leg[14]

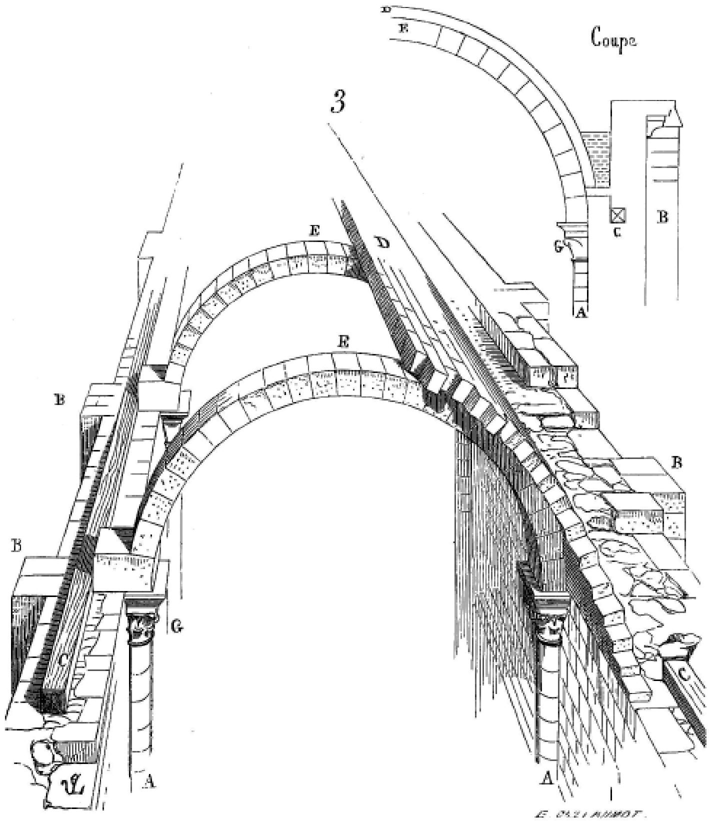


Figure 8
Viollet-le-Duc. Perspective drawing section of a barrel vault, reinforced with transverse ribs, exterior wall buttresses and interior engaged columns[15]

Viollet-le-Duc knew just as well as Willis the detail stereotomy of the ribs in medieval vaults, and whether or not they tied to the infill panel above. But whether those ribs' appearance corresponds narrowly to the structural reality of the vault would not be of great significance for him. The church he considers in its totality, as a unified organism, following one broad structural behaviour. The way the ribs appear to the eyes is the "overall" expression of that totality. Ultimately, it is the vitality and verve of the French medieval masons that he seeks to capture, the "outpouring of force and imagination" (Viollet-le-Duc 1854–1868, 2:339) that overtook French architecture in the twelfth and thirteenth centuries.

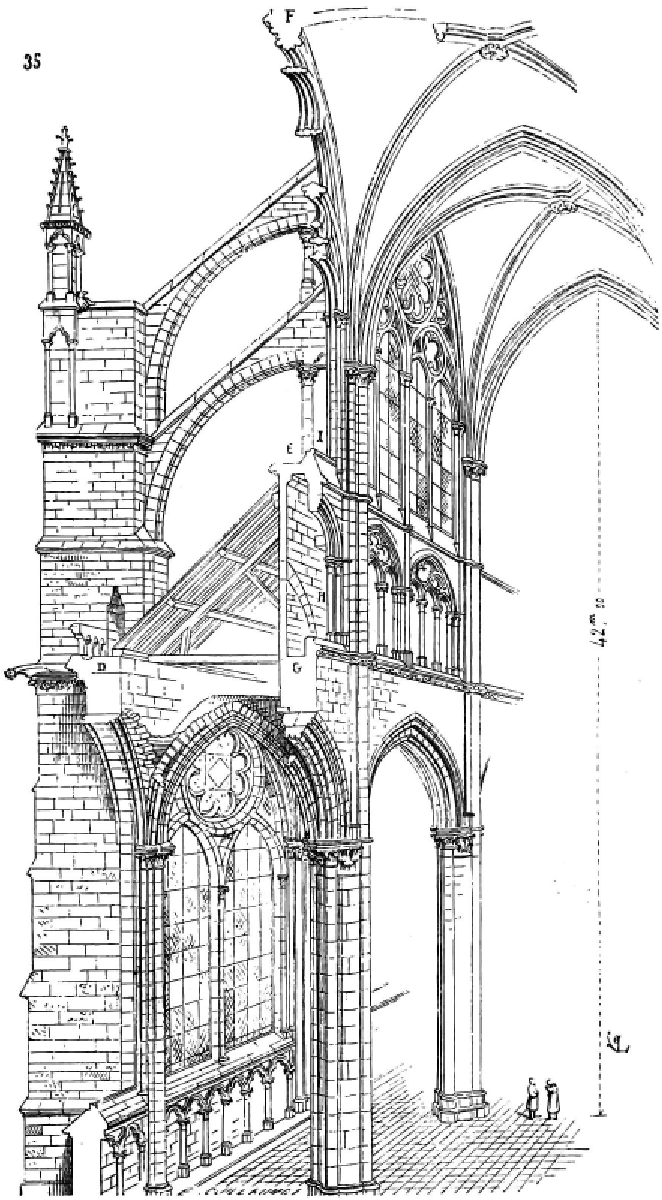
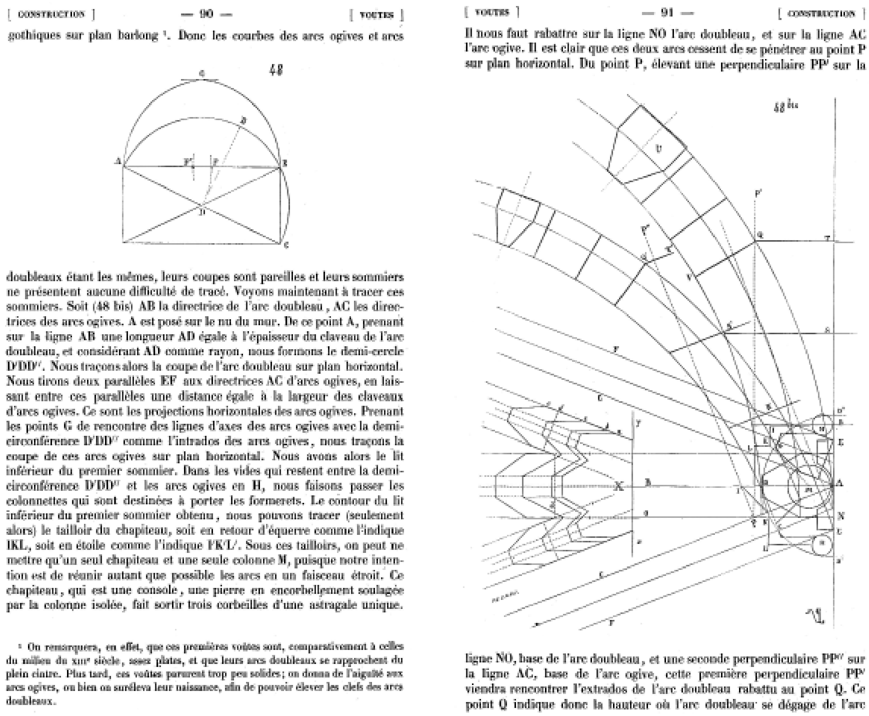


Figure 9
Viollet-le-Duc. Nave of the Amiens Cathedral[16]

Figure 10
Church of Sainte-Madeleine at Vézelay, view of the nave



[CONSTRUCTION] — 90 — [VOUTES]

gothiques sur plan barlong [1]. Donc les courbes des arcs ogives et arcs doubleaux étant les mêmes, leurs coupes sont pareilles et leurs sommiers ne présentent aucune difficulté de tracé. Voyons maintenant à tracer ces sommiers. Soit (48 bis) AB la directrice de l'arc doubleau, AC les directrices des arcs ogives. A est posé sur le nu du mur. De ce point A, prenant sur la ligne AB une longueur AD égale à l'épaisseur du claveau de l'arc doubleau, et considérant AD comme rayon, nous formons le demi-cercle D'DD''. Nous traçons alors la coupe de l'arc doubleau sur plan horizontal. Nous tirons deux parallèles EF aux directrices AC d'arcs ogives, en laissant entre ces parallèles une distance égale à la largeur des claveaux d'arcs ogives. Ce sont les projections horizontales des arcs ogives. Prenant les points G de rencontre des lignes d'axes des arcs ogives avec la demi-circonférence D'DD'' comme l'intrados des arcs ogives, nous traçons la coupe de ces arcs ogives sur plan horizontal. Nous avons alors le lit inférieur du premier sommier. Dans les vides qui restent entre la demi-circonférence D'DD'' et les arcs ogives en H, nous faisons passer les colonnettes qui sont destinées à porter les formerets. Le contour du lit inférieur du premier sommier obtenu, nous pouvons tracer (seulement alors) le tailloir du chapiteau, soit en retour d'équerre comme l'indique IKL, soit en étoile comme l'indique FK'L'. Sous ces tailloirs, on peut ne mettre qu'un seul chapiteau et une seule colonne M, puisque notre intention est de réunir autant que possible les arcs en un faisceau étroit. Ce chapiteau, qui est une console, une pierre en encorbellement soulagée par la colonne isolée, fait sortir trois corbeilles d'une astragale unique.

[1] On remarquera, en effet, que ces premières voûtes sont, comparativement à celles du milieu du XIIe siècle, assez plates, et que leurs arcs doubleaux se rapprochent du plein cintre. Plus tard, ces voûtes parurent trop peu solides; on donna de l'aiguïté aux arcs ogives, ou bien on suréleva leur naissance, afin de pouvoir élever les clefs des arcs doubleaux.

[VOUTES] — 91 — [CONSTRUCTION]

Il nous faut rabattre sur la ligne NO l'arc doubleau, et sur la ligne AC l'arc ogive. Il est clair que ces deux arcs cessent de se pénétrer au point P sur plan horizontal. Du point P, élevant une perpendiculaire PP' sur la ligne NO, base de l'arc doubleau, et une seconde perpendiculaire PP'' sur la ligne AC, base de l'arc ogive, cette première perpendiculaire PP' viendra rencontrer l'extrados de l'arc doubleau rabattu au point Q. Ce point Q indique donc la hauteur où l'arc doubleau se dégage de l'arc

Figure 11
Viollet-le-Duc. Spread pages containing diagrams that show the tracing of the *arcs ogives* and the *arcs-doubleaux*[17]

The occasional slippage between reality and appearance was insignificant within the overall performance.

When he studies the geometrical procedures of masons, it is only insofar as it can capture the main idea and the resourcefulness and ingenuity of the French mason in seeking to achieve it. His impatience with abstraction comes through particularly well in the article “Construction” in volume 4 of his *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle*. At the end of a long reasoning resorting to descriptive geometry and complex diagrams to show the precise tracing of the *arcs ogives* and the *arcs-doubleaux* (Fig. 11), he feels the need to synthesize the overall idea through one striking visual rendition. He explains:

> In order to insure that even those people not familiar with descriptive geometry can understand the operation that we have just traced, we suppose (48 *ter*) the three spring-

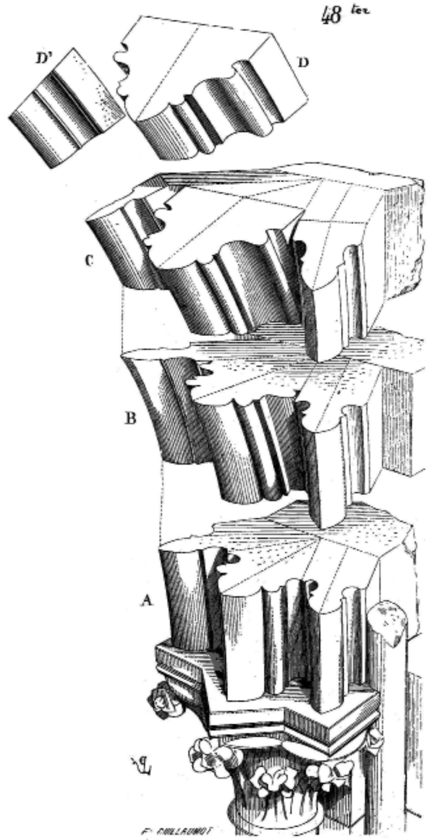


Fig. 12
Viollet-le-Duc. Cut-off perspective of the springers[18]

> ers of the preceding figure seen one above the other in perspective and with its mouldings (Viollet-le-Duc 1854–1868, 4:92). (Fig. 12)

The drawing is one of Viollet-le-Duc's most celebrated. It gives us all at once a strong feel for the intricacy and imbrication of the stones, and the vitality that runs through them. The various stones of the ribs are magically pulled apart, and the faint delineation of the geometrical matrix reveals delicately but efficiently some hint at the geometrical procedure that generated its form. What we are witnessing is not the process of setting heavy stones in place, but the idea of the medieval vault emerging from the medieval mason's mind.

Willis also sought to produce synthetic drawings for his analysis. His axonometric views of British fan vaults are equally famous and at least as inventive as Viollet-le-Duc's rich graphic repertoire (Fig. 5). Their greatness lies in their capacity to convey visually, at one glance and to scale, a complex vaulting system from an abstract point of view, where the observer is everywhere and nowhere. This intimate merging of reality with abstraction reflects perfectly well Willis's method, combining empirical evidence with mathematical analysis. As there are no vanishing points in axonometric projection, infinity is introduced, just as in mathematics. The axonometric drawing, which allows us to "see" abstractly, thus highlights how embedded within Willis's method is the slippage between reality and perception, or between the decorative and the mechanical.

In contrast, Viollet-le-Duc's exploded perspective of the springing point of the Gothic vault makes us witness a constructive event; we enter or envision the mind of the architect at work. His representation is equally embedded in abstraction as Willis's axonometry insofar as the "exploded" view is a fantasy. That Viollet-le-Duc chose to represent a generalized, idealised condition rather than any church in particular furthers emphasizes that abstract dimension. Yet his drawing makes us participate immediately and imaginatively in the act of building a Gothic church. Willis's axonometry, and by extension his whole method, is a mathematization of the real as a form of scientific empowerment. Viollet-le-Duc's explosion is nothing less than the reawakening of the Gothic spirit, giving off a prodigious and contagious sense of construction.

The comparison between Willis and Viollet-le-Duc is a paradigmatic one, showing intimately what differentiates the research method of the professor, burdened with the need to remain scrupulous and precise, from that of the architect, burdened with the task of regenerating the art of his nation. Both reflect a "modern" ideological standpoint. But whereas the former establishes an antiquarian relationship with the past, the latter seeks the unity of a single great collective story.

Notes

1. Bibliographical references appear at the end of the essay.
2. See bibliographical references.
3. In his genealogy of modern architecture, Reyner Bahnam (1967, 14) makes the work of Willis the direct and most immediate source of Viollet-le-Duc's structural rationalism. In 1977, the engineer and architectural historian Robert Mark (1977) published a short essay comparing Willis to Viollet-le-Duc, concluding that the former's emphasis was on geometry, and the latter on structure. He notes the paradox that it was Willis, the prominent engineer, who shunned structural considerations, and not Viollet-le-Duc, the self-trained architect with a literary background. He attributes this difference in approach to the nature of medieval High Gothic and the contemporary revival in

the two countries. First, English Gothic never attained the technical prowess of its French counterpart. Second, the intellectual climate was different: whereas in England the Gothic revival "looked backwards," in France it looked forward to new solutions.

Art historian, Louis Grodecki (1980, 123) sees Willis's work as comparable to Viollet-le-Duc, only less coherent and complete.

More recently, architectural historian Alexandrina Buchanan (2013) maintains that Willis's omission of structural considerations was because of his engineering interests, not despite of them, and contrasts his approach "the rationalism" of the younger Pugin and Viollet-le-Duc. The two figures return in her study in the Lincoln cathedral controversy, when Willis and Viollet-le-Duc expressed opposite views with regard to the French derivation of its architecture (Buchanan 2013, 201).

Martin Bressani (2015) places Willis's early work in the larger, European context of archaeologists and scholars of the early 19th century who turned to Gothic construction as a historical "puzzle." He sees affinities between Viollet-le-Duc and Willis, but only in terms of their graphic affinities: Willis's "peeling away" illustration of an impost, drawn for the "Masonry" heading in the 5th edition of Parker's *Glossary* (1850), and its relation to the text in the layout of the page, would prefigure the *Dictionnaire raisonné*'s illustrations (Bressani 2014, 247).

4. See Mérimée's letter to Jenny Dacquin dated 15 June 1850, in which he writes having met "Reverends" in both Cambridge and Oxford (Mérimée 1947, 6: 57). That Mérimée and Viollet-le-Duc would have met "Reverend" Robert Willis on that occasion finds indirect confirmation from the fact that, a few years later, Mérimée writes to Viollet-le-Duc to invite him to have dinner with "our friend Willis from Cambridge." See Mérimée (1961, 365).
5. For example, Willis's method of the horizontal *surface of operation* is employed to obtain the complex stone shapes in the ribs of *lierne* vaults. After showing the series of geometrical projections in the text and diagrams, Willis affirms that "that this method is in principle the one which was really employed by our workmen can scarcely be doubted after the examination of existing examples." The shape of the boss stones obtained in his diagram coincides in all its angles with specimens that he found in the nave of Canterbury Cathedral and the ruins of a capital vault which was taken down with Lanfranc's Tower (Willis 1842, 35). In a different instance, he notes with regard to his method for the construction of a vault with *tiercerons* that "it must be clearly understood that I do not suppose the method […] to be a restoration of ancient practice." However, it allows to understand in depth and imitate the arrangement of that kind of vault (Willis 1842, 23).
6. Willis describes the evolution of the After Gothic in his *Remarks on the Architecture of the Middle Ages*, *especially of Italy,* noting:

   > In the After Gothic of Germany, foliation came in for its share of that fanciful rage for intricacy, by which that style is so oddly distinguished above every other, except the Flamboyant of France, equally whimsical in another way. And I cannot help indulging perhaps in a little national vanity, when I contrast the elegance, beauty, and architectural fitness of our own After Gothic, or Perpendicular, with the puerilities that too often disfigure the coeval styles of our rivals." (Willis 1835, 47)

7. Willis points to three elements, geometrically dependent upon each other, to be determined in the design of vaults: the curvature of the ribs, the form of the ridges, and the middle plan of the spandrel solid. If two of them are determined, the third one follows

as a mater of course. The ridge and the middle plan are immediately appreciable by the eye, so that it is these two that should be selected for determination when designing a vault (Willis 1842, 23). The middle plan (a horizontal section in the solid spandrel) is an abstract notion and it is employed to give desired forms to the spandrel solid. It is a crucial element, as it "affects the character and appearance of the vault so materially" (Willis 19, 1942). The term may not have been known to the medieval architects, but Willis argues that they deliberately varied the middle plan to improve the appearance of their vaults.

8. From Plate 12 in "Mémoire de M. Willis sur la construction des voûtes au moyen âge," *Revue générale de l'architecture et des travaux publics,* 1843. reproduced and combined in one plate from various diagrams and drawings in "On the Construction of the Vaults of the Middle Ages", *Transactions of the Royal Institute of British Architects of London*, 1842.
9. From Fig. 26, Plate 17, and Fig. 27, Plate 18, in "Mémoire de M. Willis sur la construction des voûtes au moyen âge," *Revue générale de l'architecture et des travaux publics,* 1843 (reproduced from Fig. 25, Plate I, and Fig. 26, Plate II in "On the Construction of the Vaults of the Middle Ages", *Transactions of the Royal Institute of British Architects of London*, 1842). In the first publication of Willis's paper in *Transactions of the Royal Institute of British Architects of London*, 1842, only a quarter of the vault in Fig. 25–26 is represented in the plan and section. In the Plates in *Revue générale de l'architecture et des travaux publics,* 1843 the quarters are expanded into half of the vaults.
10. From Figs. 32, 33, Plate 19 in "Mémoire de M. Willis sur la construction des voûtes au moyen âge," *Revue générale de l'architecture et des travaux publics,* 1843 (reproduced from Fig. 27, 28, Plate I in "On the Construction of the Vaults of the Middle Ages", *Transactions of the Royal Institute of British Architects of London*, 1842). In the first publication of Willi's paper in *Transactions of the Royal Institute of British Architects of London*, 1842, only a quarter of the vault is represented in the plan and section. In the Plates in *Revue générale de l'architecture et des travaux publics,* 1843 the quarters are expanded into half of the vaults.
11. From Viollet-le-Duc, "De la construction des édifices religieux en France, depuis le commencement du christianisme jusqu'au XVI siècle." *Annales archéologiques* (1847): 247-255.
12. From Fig. 34, Plate 20 in "Mémoire de M. Willis sur la construction des voûtes au moyen âge," *Revue générale de l'architecture et des travaux publics,* 1843 (reproduction of Fig. 29, Plate III, in "On the Construction of the Vaults of the Middle Ages", *Transactions of the Royal Institute of British Architects of London*, 1842)
13. From Viollet-le-Duc, *Histoire d'un dessinateur, comment on apprend à dessiner*, 1879, p. 283, Fig. 105.
14. From Viollet-le-Duc, *Histoire d'un dessinateur, comment on apprend à dessiner*. Paris: J. Hetzel, 1879, p. 28, Fig. 106.
15. From Viollet-le-Duc, *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle*, vol. 4, p.15, Fig. 3, under the heading "Construction".
16. From Viollet-le-Duc, *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle*, vol. 1, p. 203, Fig. 35, under the heading "Architecture".
17. From Viollet-le-Duc, *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle*, vol. 4, p. 90–91, Fig. 48–48bis, under the heading "Construction".

18. From Viollet-le-Duc, *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle*, vol. 4, p. 93, Fig. 48*ter,* under the heading "Construction".

Reference list

Banham, Reyner. 1960. *Theory and Design in the First Machine Age*. London: Architectural Press.

Bressani, Martin. 2014. *Architecture and the Historical Imagination: Eugène-Emmanuel Viollet-le-Duc 1814–1879*. Farnham (Surrey), Burlington (VT): Ashgate Publishing Limited.

Buchanan, Alexandrina. 2013. *Robert Willis and the Foundation of Architectural History*. Woodbridge: The Boydell Press, Cambridge University Library.

Louis Grodecki. 1980. "Viollet-le-Duc et sa conception de l'architecture gothique." *Actes du colloque international Viollet-le-Duc – Paris 1980*. Paris: Nouvelles Éditions Latines.

Mark, Robert. 1977. "Robert Willis, Viollet-le-Duc and the Structural Approach to Gothic Architecture." *Architectura* 7: 52–64. Reprinted in *The Engineering of Medieval Cathedrals*, edited by L. T. Courteney, Aldershot, 1997.

Mérimée, Prosper. 1947. *Correspondance générale*, Maurice Partutier ed., volume 6. Paris, Le Divan.

Mérimée, Prosper. 1961. *Correspondance générale*. Supplement. Toulouse: Édouard Privat.

Nicholson, Peter. 1834. *The Builder's and Workman's New Director*. New enlarged edition. London: J. Taylor.

Willis, Robert. 1835. *Remarks on the Architecture of the Middle Ages*, *especially of Italy.* Cambridge: J. & J.J. Deighton, 1835.

Willis, Robert. 1842. "On the Construction of the Vaults of the Middle Ages." *Transactions of the Royal Institute of British Architects of London*, I, part II: 1–69.

Willis, Robert. 1843. "Mémoire de M. Willis sur la construction des voûtes au moyen âge." *Revue générale de l'architecture et des travaux publics* 4: cols. 3–14, 289–304, 481–507 and 529–547.

Viollet-le-Duc. 1844–1847. "De la construction des édifices religieux en France, depuis le commencement du christianisme jusqu'au XVI siècle." *Annales archéologiques,* 1 (1844): 179–86; 2 (1845): 78–85, 143–150, 336–349; 3 (1845): 321–336; 4 (1846): 266–283; 6 (1847): 194–205, and 247–55.

Viollet-le-Duc. 1854–1868. *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle.* 10 Vols. Paris: B. Bance and A. Morel et Cie.

Viollet-le-Duc. 1879. *Histoire d'un dessinateur, comment on apprend à dessiner*. Paris: J. Hetzel.

Un secolo di ricezione di Willis in Italia e in Francia (1835-1935)

Simona Talenti

Il silenzio della letteratura architettonica e tecnica italiana

Grande studioso della scienza delle costruzioni e delle tecniche costruttive, Salvatore di Pasquale ha pubblicato nel 1996 un testo di riferimento per quanto riguarda la storia delle conoscenze tecnico-scientifiche: *L'arte del costruire. Tra conoscenza e scienza* (Di Pasquale 1996). Se a Viollet-le-Duc viene dedicato ampio spazio in quanto è considerato dall'autore come il primo ad avere saputo "tradurre quei sentimenti di leggerezza, di meraviglia, di stupore, che avevano accompagnato la riscoperta e la rilettura del gotico…in un linguaggio meno fantasioso e più rispondente alla natura meccanica dei nuovi problemi che quel modo di costruire poneva, e risolveva", il nome di Willis non viene invece neppure menzionato (Di Pasquale 1996, 404). Perfino nel capitolo dedicato a "La distinzione tra costruzione e struttura", le riflessioni dello studioso inglese vengono completamente offuscate dalla gloria e dal successo internazionale della vicenda francese, letta attraverso le opere di Viollet-le-Duc e dei suoi critici, l'ingegnere Victor Sabouret e l'architetto Pol Abraham. Se la voce "Gotico" dell'*Enciclopedia dell'arte* della Treccani rimanda all'opera di Willis —considerandolo un precursore per quanto riguarda l'analisi dei comportamenti strutturali ma soprattutto per "l'uso moderno di unire all'archeologia lo studio delle fonti scritte"— la ragione può essere facilmente individuata nella nazionalità e nelle specificità del redattore dell'articolo: si tratta infatti del grande studioso britannico di arte medievale, Peter Kidson (Kidson 1996, np).

L'atteggiamento di Salvatore di Pasquale è sintomatico della ridotta fortuna critica di Willis e della sua fondamentale assenza dalla letteratura architettonica

ed ingegneristica italiana otto-novecentesca nella quale Ruskin e Viollet-de-Duc occupano i ruoli principali. Se è vero, come afferma Luciano Patetta, che il "medievalismo italiano si fonda soprattutto sui contributi francesi, inglesi e tedeschi che circolano in Italia in lingua originale o tradotti" visto che "molto modesti sono, in tutto l'Ottocento, i contributi italiani ad una conoscenza archeologica dell'architettura del Medio Evo", altrettanto vero sembra abbiano raggiunto l'Italia solo le pubblicazioni di un certo prestigio o comunque quelle che avevano raggiunto un discreto successo nel loro paese: le opere di Essex, Rickman, Caumont, o Viollet-le-Duc (Patetta 1975, 260). Alcuni testi inglesi, come il celebre *An historical essay* (1835) di Thomas Hope sono stati anche tradotti rapidamente in italiano —l'edizione curata dall'ing. Gaetano Imperatori risale al 1840 —, mentre un sunto del lavoro di Street sull'Italia è stato pubblicato nel 1858 sul *Giornale dell'Ingegnere, Architetto e Agronomo* (Magister 1858). Ma l'interesse degli autori italiani, il cui approccio storico ed analitico risentiva ancora profondamente del sistema di catalogazione e raccolta distintivo della cultura antiquaria, verteva essenzialmente sui valori stilistici. Che si tratti del lavoro condotto da Pietro Selvatico *Sulla Architettura e sulla Scultura in Venezia dal Medio Evo sino ai nostri giorni* (Selvatico 1847) o della *Storia dell'architettura in Italia* redatta da Amico Ricci tra 1857 e 1859 (Ricci 1857–59), la metodologia storica non si apparentava in nulla agli studi costruttivi e tecnici intrapresi in Inghilterra da Willis. Peraltro, Pietro Selvatico —così come tutta la cerchia di intellettuali veneti — sembrava risentire maggiormente dell'influenza della cultura storiografica francese e tedesca.[1] Lo studioso veneziano si è limitato a menzionare in una nota a piè di pagina il lavoro del reverendo inglese del 1835 (Willis 1835) —traducendo il titolo in italiano come "Osservazioni sulla Architettura delle età mezzane" (Selvatico 1847, 94). Selvatico intendeva mettere a confronto le diverse ipotesi riguardanti le origini dell'architettura medievale. E così accanto al nome di Willis, figuravano diverse pubblicazioni francesi (firmate da Coste, Michelet ecc.) così come la *Storia ed analisi dei principali stili di architettura* (1835) di Edward Boid: tutti lavori nei quali Selvatico leggeva l'"architettura araba come elemento ed origine dell'archi-acuta" (Selvatico 1847, 94). Ciononostante l'intellettuale veneziano mostrava alcune assonanze con il metodo classificatorio utilizzato dal professore inglese nella sua prima pubblicazione. Nell'opera *Sulla architettura e sulla scultura in Venezia*, Selvatico ha pubblicato infatti una sorta di tabella/indice schematico con indicazione del luogo in cui si trovava il manufatto analizzato, degli elementi più significativi, della data di costruzione dell'edificio e dell'autore dell'opera: uno schema sintetico che ricordava il format pubblicato da Willis nel libro del 1835 sul gotico italiano. Ma l'obiettivo ultimo di Selvatico non è stato solo quello di dimostrare l'autonomia dell'architettura medievale italiana chiamata "lombarda", bensì di voler con-

— 510 —

LUOGO	OGGETTI OSSERVABILI	EPOCA	AUTORI	PAGINA dell'Opera
Campanile de' Frari	Cominciato	1361	*Jacopo Celega*	125
	Compiuto	1396	*Paolo Celega*	Id.
di S. Sofia	Tutti del medio evo e specialmente del sec. XIV.			143
di S. Apollinare				Id.
di S. Michele di Murano				Id.
di S. Pietro a Murano				Id.
di S. Stefano				Id.
di S. Barnaba				Id.
di S. Polo		1375		Id.
di S. Giovanni Elimosinario		cominc. 1398 finito 1410		Id.
di S. Michele Arcangelo	»	1456	*Marco Turi*	250
di S. Maria Nova	»	1498	*Matt. Fontana*	251
di S. Maria dell'Orto	Stile lombardesco		»	253
di S. Pietro di Castello	Idem	1480	»	255
dei SS. Apostoli	Cella	XVIII secolo	*Andrea Tirali*	436
di San Giorgio Maggiore		Id.	*P. Ben. Buratti*	473
Casa Al Campo dei Mori	Bisantino-Araba	XIII secolo		97
Falier (al Ponte dei SS. Apostoli)	Bisantino-Araba	XIV secolo		Id.
a S. Agostino (Rio Terrà)	Bassorilievo	XV secolo		240
Albrizzi	Testa di Elena in marmo	XVIII secolo	*Ant. Canova*	486
Cicognara	(Testa di Beatrice in marmo) (Busto del comm. Cicognara)	XVIII secolo	*Ant. Canova*	486
S. Clemente in isola (chiesa)	Cappella detta la Santa Casa di Loreto	1646		436
	Monumento di Girolamo Gradenigo, patriarca d'Aquileia	XVII secolo		Id.
	Monum. di Giorgio Morosini	1676	*Giusto Le Curt*	441
	id. di Pietro Morosini	1682	*Id.*	Id.
	Bassorilievo in bronzo	XVII secolo	*Camillo Mazza*	445
Colonne in Piazzetta	Portate dall'Arcipelago	1125		76
	Rizzate	1170	*Nicc. Barattieri*	77
	Capitelli e basi	»		Id.
Corpo di guardia (all'Ascensione)	Architettura	XIX secolo	*Lorenzo Santi*	484

Figura1

Schema/tabella riassuntiva: Selvatico, Pietro. 1847. *Sulla Architettura e sulla Scultura in Venezia dal Medio Evo sino ai nostri giorni*. (Venezia:· Ripamonti Carpano, 510)

tribuire a fornire, attraverso lo studio e le ricerche storiche sull'età di mezzo, un supporto alla pratica dell'architettura contemporanea. Le illustrazioni pittoresche e il testo descrittivo di Selvatico rivelavano tutta la distanza che separava l'autore italiano da Willis e tutta l'ambiguità dello storico veneziano che ha sempre cercato un compromesso tra il razionalismo lodoliano, l'attenta lettura di Pugin e il simbolismo ruskiniano (Bernabei 1974).

Nel corso della seconda metà dell'Ottocento, la fortuna critica di Willis nella storiografia architettonica italiana non ha subìto fondamentali modifiche, ma ha assunto connotati diversi. Non è più soltanto il retaggio della disciplina letteraria ed antiquaria ad influire sul metodo di approccio storico ai monumenti. Si potrebbe avanzare l'ipotesi che la presa di coscienza del ruolo della scienza meccanica nella disciplina architettonica, abbia suscitato un malessere nella categoria degli architetti —da cui provenivano quasi sempre gli storici dell'architettura— legato al progressivo ridimensionamento della loro professione. Quelle conoscenze tecniche e costruttive che da sempre si erano sposate con le capacità creative di produrre la "bellezza", erano diventate, a partire dalla metà del XIX secolo, una prerogativa del mondo dei matematici ma soprattutto degli ingegneri, con cui gli architetti (italiani ma non solo) hanno instaurato un rapporto non sempre facile e limpido. L'assenza, nella letteratura architettonica italiana, di qualunque rimando alle interpretazioni meccaniche avanzate da Willis, potrebbe in parte trovare spiegazione nell'insicurezza e nel timore che gli architetti —ma anche, più in generale, tutti coloro che studiavano la storia della disciplina— hanno cominciato a manifestare nei confronti degli aspetti tecnici, costruttivi e strutturali che non rientravano più nel loro bagaglio culturale e nella loro formazione. Va ricordato infatti che in Italia l'insegnamento dell'architettura avveniva in seno alle Accademie dove lo studente riceveva una formazione essenzialmente artistica (De Stefani 1992; Ricci 1992). Intorno al 1865 l'Istituto Tecnico Superiore di Milano aveva inaugurato, grazie all'impegno e al contributo di Camillo Boito, una sezione per "architetti civili" con lo scopo di creare una nuova figura professionale in grado di combinare le competenze tecniche e costruttive degli ingegneri con le qualità artistiche degli architetti (De Stefani 1992). Ma il nuovo corso, aperto anche presso altri Istituti italiani, ha avuto un successo molto ridotto e pochissimi allievi. La *querelle* tra architetti ed ingegneri si è fatta dunque sempre più flagrante.

Considerato il ruolo di Boito come mediatore tra cultura scientifica ed artistica —lui stesso insegnava all'Accademia di Belle Arti di Milano e all'Istituto tecnico superiore nella stessa città— risulta alquanto strano che questo fervente sostenitore della necessità di fornire agli architetti della seconda metà dell'Ottocento un insegnamento tecnico, abbia poi trascurato completamente, nei suoi studi, l'apporto scientifico di Robert Willis. Nella celebre pubblicazione incentrata per-

altro proprio sull'architettura italiana del Medioevo (Boito 1880), Boito (ex-allievo di Selvatico a Venezia) ha rivolto il suo sguardo al valore etico di sincerità dell'architettura medievale, intesa come fonte d'ispirazione per quello stile futuro che doveva nascere nel XIX secolo. Non è ovviamente da escludere che l'opera di Willis non gli fosse completamente estranea. Se è vero infatti che Camillo Boito —teorico e restauratore oltre che architetto e professore— non ha mai menzionato in *Architettura del Medio Evo in Italia* il nome di Willis, purtuttavia l'utilizzo del termine "struttura decorativa", distinta dalla "forma ornamentale" (Boito 1880, 275), potrebbe fare pensare ad una interpretazione della distinzione operata dal reverendo inglese tra "decorative construction" e "mechanical construction", che lo stesso Willis chiamava a volte "Decorative and Mechanical structures" (Willis 1835, 5).

Ci si sarebbe potuti aspettare che nelle Scuole di Applicazione per Ingegneri e in particolare all'interno dei corsi di "Architettura tecnica" istituiti intorno agli anni 1870–1880 con l'obiettivo dichiarato di favorire il legame tra conoscenze architettoniche e sapere tecnico-scientifico, avesse preso piede un insegnamento più simile alle lezioni tenute da Willis a Cambridge. Nei corsi di "Architettura tecnica", convergevano infatti differenti discipline —dal disegno alla storia dell'architettura, dalla composizione al restauro e all'urbanistica oltre alle discipline tecniche, costruttive e tecnologiche— nell'intento di fornire tutti gli strumenti potenzialmente necessari ai futuri ingegneri civili per potersi confrontare con il progetto di architettura (Talenti 2012). I titolari di questo insegnamento, nelle diverse Scuole italiane, affrontavano ed analizzavano spesso e volentieri gli elementi architettonici non solo dal punto di vista costruttivo, ma anche da quello storico. Ma sembra che neppure in questi corsi si sia risentita l'influenza del lavoro compiuto sul suolo britannico nel campo della meccanica dell'architettura. Gli insegnanti come l'ingegnere Attilio Muggia a Bologna, per esempio, anche quando nelle sue lezioni ha affrontato il tema della volta e dell'arco a sesto acuto (Muggia 1893–94, 112–113), ha fatto esplicito riferimento solo all'interpretazione di Viollet-le-Duc secondo il quale la crociera ogivale sarebbe derivata "dalla cupola piuttosto che da quella tipica romana risultante dall'intersezione di due volte a botte" (Muggia, 1893–94, 113). Nella sua *Storia dell'architettura* pubblicata nel 1933, Muggia ha analizzato tutto il periodo medievale senza mai citare l'autore inglese (Muggia 1933). Nella bibliografia si trovano sempre i testi dell'architetto razionalista francese, accompagnato questa volta da quelli dell'archeologo Camille Enlart e da un paio di studiosi americani.

Perfino il lavoro di Milani dal titolo *L'Ossatura murale* (Milani 1920) —menzionata da di Pasquale in quanto lavoro che si inscriveva nella metodologia di analisi messa a punto da Viollet-le-Duc— non faceva espliciti riferimenti agli studi e alle teorie di Willis, ma rinviava anch'esso unicamente alla tradizione

francese (tra cui figurava l'opera di Julien Guadet). Attento lettore dei lavori di Auguste Choisy, nonché responsabile a partire dal 1905 del corso di "Architettura tecnica" presso la Regia Scuola di Ingegneria di Roma, Giovanni Battista Milani doveva però conoscere in qualche modo l'opera di Willis. La presenza di una tavola nella quale la basilica di Massenzio era accostata alla cattedrale di Milano (Milani 1920, plate 28), rivelava una certa assonanza con i ragionamenti elaborati dal reverendo inglese nel libro sull'architettura medievale in Italia, in particolare riguardo le origini dell'ogiva. Nella prima tavola della sua pubblicazione, Willis aveva infatti inserito un disegno isometrico delle terme romane: un edificio che permetteva all'autore di spiegare "the origin of many of the parts of the Gothic Cathedrals" (Willis 1835, 189).

Se la letteratura architettonica italiana ha continuato a non considerare l'opera di Willis come un valido riferimento critico meritevole di essere studiato ed esplicitamente citato, sembra però che intorno agli inizi del Novecento un brillante ingegnere con una degna formazione artistica se ne sia ispirato per mettere a punto il suo metodo di analisi storica e per spiegare la bellezza dell'architettura proprio attraverso la meccanica. Si tratta di Gustavo Giovannoni, laureato in ingegneria nel 1895, assistente dal 1899 del corso di "Architettura tecnica" alla Scuola di applicazione di Roma e infine docente e direttore (tra il 1927 e il 1933) presso la neo-nata Scuola Superiore di Architettura della capitale. L'approccio di Giovannoni allo studio dell'architettura antica —in particolare quella romana (Giovannoni 1925)— era sicuramente debitore nei confronti della tradizione razionalista francese, ma in qualche modo sembrava legarsi anche con il metodo di Robert Willis il quale aveva già cercato, nella prima metà dell'Ottocento, di andare al di là del tradizionale approccio antiquario, coniugandolo con l'esperienza visiva (Chiovelli 2007). Lo studio imperniato sull'osservazione diretta dei manufatti, l'attenzione alla comprensione degli aspetti costruttivi, l'analisi geometrica e spaziale caratterizzavano i lavori di Giovannoni così come avevano permesso allo studioso inglese di redigere le sue pubblicazioni e disegnare le sue numerose isometrie. Il metodo di analisi messo a punto da Willis basato sulla necessità di coniugare la disamina delle fonti documentali con quella del rilievo dell'edificio stesso e della comprensione dell'organismo strutturale, ha contraddistinto anche il sistema utilizzato da Giovannoni nei suoi studi. Contrapponendosi agli storici dell'arte e alla corrente di stampo crociano seguita da Lionello Venturi (professore dello stesso Giovannoni all'Università di Roma) che focalizzava lo sguardo sugli aspetti stilistici e faceva rientrare la storia dell'architettura all'interno della più ampia disciplina della storia dell'arte, l'ingegnere romano ha ritenuto necessario capire la costruzione dell'edificio e ha pertanto deciso, nei suoi lavori, di accompagnare le immagini fotografiche con rilievi ed attenti studi degli edifici storici, mettendo così in evidenza le specificità della disciplina architettonica.

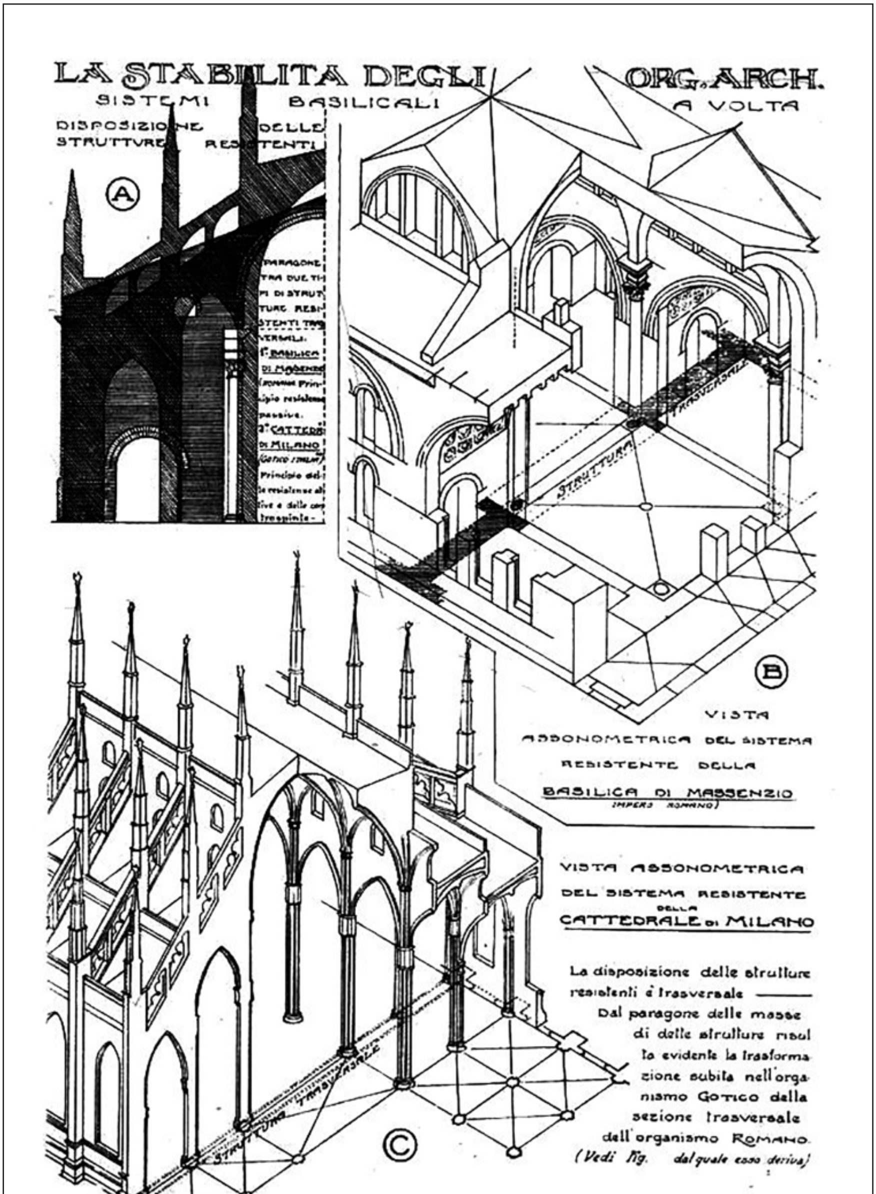


Figura 2
Veduta assonometrica del sistema costruttivo della basilica di Massenzio: Milani, Giovanni Battista. 1920. *L'ossatura murale* (Torino: Soc. Italiana di Edizioni Artistiche, C. Crudo e C., 1: plate 28)

L'insegnamento professato e divulgato da Willis più di cinquant'anni prima, attraverso le sue diverse pubblicazioni e in particolare le monografie sulle cattedrali inglesi, sembrava pertanto trovare un campo di applicazione nella metodologia storica portata avanti da Giovannoni. Resta comunque il fatto che le affinità tra Willis e il mondo dell'architettura italiano, sono deboli, timide e mai dichiarate. Per dirla assieme a Frankl, "he influenced large circles in England, though in other countries he seems to have been for the time overlooked" (Frankl 1960, 531). Effettivamente, l'opera del reverendo inglese ha avuto pochissime ricadute e pochissimo seguito sul suolo italiano. Forse l'unico settore in cui è stata individuata una vera influenza, ufficialmente riconosciuta, è il campo della pura meccanica. La pubblicazione del 1841 *Principles of Mechanism* ha avuto infatti un certo successo anche a sud delle Alpi (Willis 1841). Carlo Ignazio Giulio, ingegnere civile e docente di meccanica nonché di matematica presso la sede universitaria di Torino tra il 1832 e il 1844, si è rifatto frequentemente alla scuola di Willis e al sistema di "classificazione delle macchine in base al meccanismo costituente, non alla trasformazione del moto" (Marchis 2002). Marchis, nel suo saggio "Dall'ingegneria come pratica, all'ingegneria come scienza" ricorda inoltre come l'ingegnere torinese si fosse ispirato al collega britannico anche quando aveva promosso una formazione professionale rivolta agli operai all'interno dell'Accademia delle Scienze di Torino, imitando l'esperienza che Willis aveva approntato in Inghilterra attraverso i suoi corsi serali (Marchis 2006).

Willis in Francia tra iniziale entusiasmo e mancato tributo

Sul suolo francese, l'iniziale entusiasmo per i lavori di Willis da parte di architetti e storici di diversa formazione, ha lasciato ben presto il posto ad un rapido oblio delle pubblicazioni dello studioso inglese. La sollecitudine nonché la breve durata del successo è chiaramente deducibile dai riferimenti e dai rimandi degli autori francesi. Se nel 1843 Louis Batissier aveva inserito nella bibliografia del libro *Eléments d'archéologie nationale* il testo di Willis accanto a quelli di Boid e Rickman (Batissier 1843, 582), due anni più tardi, nella sua celebre *Histoire de l'art monumental dans l'antiquité et au moyen âge* (Batissier 1845), il nome dello studioso britannico è già scomparso. Va inoltre precisato che anche quella poca popolarità raggiunta dal professore di Cambridge in Francia, è profondamente legata ad un uso "operativo" degli studi sul Medioevo. Come avremo occasione di sottolineare, la cultura architettonica francese ha infatti pensato di poter utilizzare il lavoro di Willis in vista della definizione e della creazione di un'architettura contemporanea. Il legame con il presente e con la corrente neogotica non va dunque sottovalutato, soprattutto se si pensa che gli storici dell'architettura francesi erano quasi sempre degli architetti.

Le considerazioni che Arcisse de Caumont ha espresso nel 1836 nella sua *Histoire sommaire de l'architecture religieuse* rendono conto di un apprezzamento estremamente positivo dell'opera del "Jacksonian professor" (Caumont 1836). Il volume dell'archeologo francese è uscito un anno dopo la pubblicazione di *Remarks* (Willis 1835). Nel capitolo dedicato all'"État de la science", Caumont non si è limitato a menzionare gli studi del collega britannico ma ne ha ammirato i risultati, utilizzando nei confronti di tale lavoro, termini come "considérations extremement élevées", "importante et instructive dissertation", "catalogue extremement intéressant", e parlando poi delle illustrazioni come di "15 planches excellentes" (Caumont 1836, 15). Entrambi gli autori si rifacevano alle scienze naturali e al loro metodo di classificazione, nonché al celebre e popolare trattato stilistico di Thomas Rickman[2] (Rickman 1815; Chiovelli 2007). Ma Caumont era convinto della propria modernità ed originalità metodologica e del suo ruolo di antesignano, al punto da affermare "Personne ne m'a devancé dans la carrière que je viens de parcourir" (Caumont, 1830–35, IV: 318). È possibile pertanto che l'archeologo francese abbia concepito lo studio statistico, documentario e topografico compiuto da Willis in Italia come il prosieguo dell'intenso lavoro di classificazione e di censimento dell'architettura medievale che egli stesso aveva iniziato fin dalla fine degli anni 1820 in Normandia. Questa interpretazione conduceva Caumont a considerare Willis come un suo epigono, permettendogli di decantare il frutto del viaggio in Italia effettuato dal collega britannico.

Ma dopo questo primo e repentino riscontro del lavoro di Willis sul suolo francese, il professore di Cambridge, come vedremo, è stato sempre più spesso sottovalutato e a volte quasi completamente dimenticato dagli storici dell'architettura così come dagli archeologi francesi della seconda metà del XIX secolo che, nel migliore dei casi, si sono limitati a citarlo in nota o in bibliografia. Al di là dell'indiscutibile relazione intellettuale nata tra lo studioso inglese e il celebre difensore del razionalismo Viollet-le-Duc sulla quale si stanno svolgendo studi approfonditi, il mondo architettonico francese ottocentesco ha intrattenuto un rapporto di distacco rispetto ai lavori di Willis. La pubblicazione del 1835 che il reverendo inglese aveva dedicato al Medioevo e in particolare al gotico italiano, non ha ovviamente riscosso un grande successo sul suolo francese dove l'architettura italiana dell'Età di mezzo ha tardato ad essere presa in considerazione e ad essere ampiamente rivalutata (Talenti 2011), contrariamente all'attenzione rivoltale dalla letteratura inglese come per esempio da Thomas Hope nel 1835 (*An historical essay on architecture*) o da George E. Street venti anni più tardi (*Brick and marble in the Middle Ages: Notes of a tour in the North Italy* 1855). Anche quando alla fine dell'Ottocento un archeologo come Camille Enlart decise di dedicare all'architettura gotica italiana un importante studio, l'approccio ha rivelato il forte e tradizionale nazionalismo del popo-

lo gallico (Kruft 1989). Il volume *Origines françaises de l'architecture gothique en Italie* pubblicato nel 1894, comprovava infatti perfettamente questa lettura dell'architettura medievale italiana la cui unica origine era individuata nelle esperienze francesi. Non è così un caso che l'autore non abbia citato in nessun momento le ipotesi avanzate da Willis nel libro dato alle stampe dopo il suo viaggio in Italia.

Gli scambi tra le interpretazioni e le teorie avanzate dagli studiosi francesi ed inglesi sembrano quindi essere avvenuti attraverso altri canali tematici e non tramite l'interesse per la declinazione italiana dello stile gotico con le sue origini autoctone e le sue peculiarità. Ma anche la pubblicazione *Architectural Nomenclature of the Middle Ages*, edita da Willis nel 1844 —poi confluita nella quinta edizione del 1850 del volume di Parker *A glossary of terms used in Architecture*— e ispirata alla tradizione dei dizionari d'architettura francesi, non ha trovato grandi ammiratori in Francia (Willis 1844). Neanche la disamina attenta dei termini dell'architettura medievale ha permesso a Willis di diventare un riferimento ineludibile per le pubblicazioni francesi dell'Otto-Novecento. Arcisse de Caumont, il cui *Cours d'antiquités monumentales* (Caumont, 1830–35) è stato citato da Willis nel suo lavoro del 1844, ha firmato nel 1846 il testo *Définition élémentaire de quelques termes d'architecture* (Caumont 1846). L'archeologo vi ha allineato le definizioni in ordine alfabetico, senza pretendere però di comporre un vero e proprio dizionario di architettura. Caumont non faceva alcun riferimento al lavoro pubblicato da Willis due anni prima, ma sembrava prendere come modello la pubblicazione di Parker *A Glossary* data alle stampe a partire dal 1836 (nella quale, però, non figurava ancora la parte elaborata dal professore di Cambridge) (Parker, 1836). Se Adolphe Berty, che ha pubblicato nell'aprile del 1845 il *Dictionnaire de l'architecture du moyen âge, contenant tous les termes techniques* (Berty 1845) poteva non essere al corrente della recentissima operazione editoriale di Willis, Daniel Ramée invece —che per altro nel secondo volume della sua *Histoire de l'architecture* edita nel 1862 aveva menzionato Willis— non doveva aver ritenuto il lavoro del reverendo inglese un testo cui fare esplicito riferimento nel suo *Dictionnaire général des termes d'architecture* del 1868 (Ramée 1868). Non diversamente si è comportato Pierre Chabat, architetto, professore di costruzioni al Conservatoire des Arts et Métiers di Parigi nonché autore di un *Dictionnaire des termes employés dans la construction* pubblicato a partire dal 1875 (Chabat 1875–78). Nonostante il suo approccio costruttivo, Chabat non faceva riferimento alcuno agli studi di Willis. A valle di questa prima indagine, seppure sommaria, sembra che gli sforzi dello studioso inglese nel mettere a punto le definizioni della terminologia architettonica medievale non abbiano riscontrato un seguito né presso gli archeologi, né presso gli storici dell'architettura e neppure presso quella categoria di architetti, come Chabat, che

avevano introdotto nel loro insegnamento e nelle loro pubblicazioni un'analisi costruttiva dei manufatti associata ad uno studio storico dei materiali.

Tra le ragioni che potrebbero spiegare una ricezione così mite e timida dei lavori di Willis, si potrebbe ipotizzare la difficoltà linguistica della lettura e della comprensione di testi piuttosto complessi redatti in inglese dallo studioso di Cambridge. A parte la sollecita traduzione pubblicata da César Daly sulla *Revue Générale de l'Architecture et des Travaux Publics* nel 1843 (Willis 1843) del lavoro sulle volte (Willis 1842), i volumi di Willis non sono mai stati tradotti in vista di un pubblico francofono. Se da una parte tale strategia commerciale poteva avere influito sulla poca fortuna critica di Willis sul suolo francese, dall'altra essa rivelava l'assenza di interesse, soprattutto nel corso della seconda metà dell'Ottocento, per gli studi e per l'approccio tecnico dello studioso britannico. La traduzione di Daly rifletteva invece l'interesse che la rivista francese aveva da sempre manifestato —e che ha continuato a manifestare fino agli anni 1860— per l'architettura medievale e per la promozione di un suo utilizzo moderno (Saboya 1991, 216). L'architetto francese, direttore della *R.G.A.T.P.*, riteneva infatti che il saggio di Willis fosse estremamente interessante e importante "sous le double rapport de l'archéologie et de la pratique moderne de l'architecture ogivale" (Willis 1843, 3). Lo scopo di Daly non era quindi soltanto legato alla pura ricerca storica e alle interpretazioni delle costruzioni gotiche. All'origine dell'interesse manifestato dall'architetto francese —così come è avvenuto in quegli stessi anni anche per Pietro Selvatico— vi era un obiettivo profondamente connesso alla nuova architettura che avrebbe trovato beneficio dall'applicazione di quei procedimenti tecnici e costruttivi messi a punto durante il Medioevo ed ora perfettamente scandagliati. Di madrelingua inglese, Daly era stato in grado di tradurre facilmente il testo integrale appena pubblicato e ricevuto dall'Istituto degli Architetti Britannici di Londra all'interno del volume *Transactions of the Royal Institute of the British Architects of London* (Willis 1843, 3). Di grande importanza erano, per Daly, anche i disegni di Willis, che però l'architetto francese "ha corretto", supponendo che gli errori derivassero dalla "étourderie" o dalla "ignorance du graveur" (Willis 1843, 3). É indiscutibile che la pubblicazione in francese sulla *R.G.A.T.P.* dello studio sulle volte abbia costituito il principale canale di diffusione del lavoro dello studioso inglese. I pochi autori che hanno menzionato il nome di Willis all'interno di pubblicazioni archeologiche, storiche o tecniche, hanno quasi tutti fatto riferimento alla tempestiva traduzione di Daly. Perfino Jules Quicherat, stimato professore di archeologia nonché direttore della prestigiosa École des Chartes, nel suo *Mélanges d'archéologie et d'histoire* edito postumo a Parigi nel 1885–86, ha citato a più riprese le interpretazioni dell'architetto inglese —considerandolo "très versé dans la connaissance du gothique" ed esperto della costruzione delle volte medievali— ma rinviando

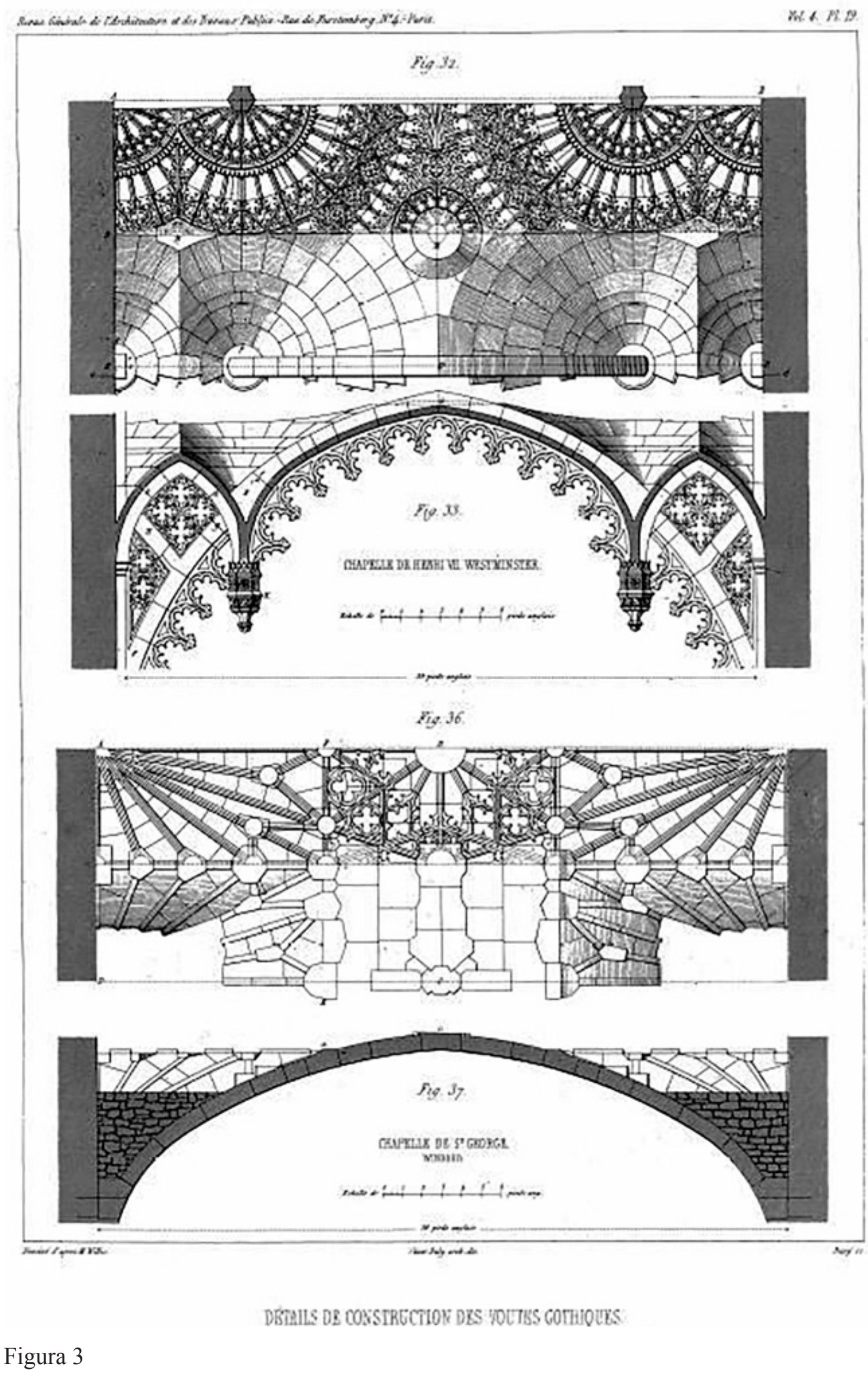


Figura 3
Tavola di Willis pubblicata da César Daly (Willis 1843, plate 19)

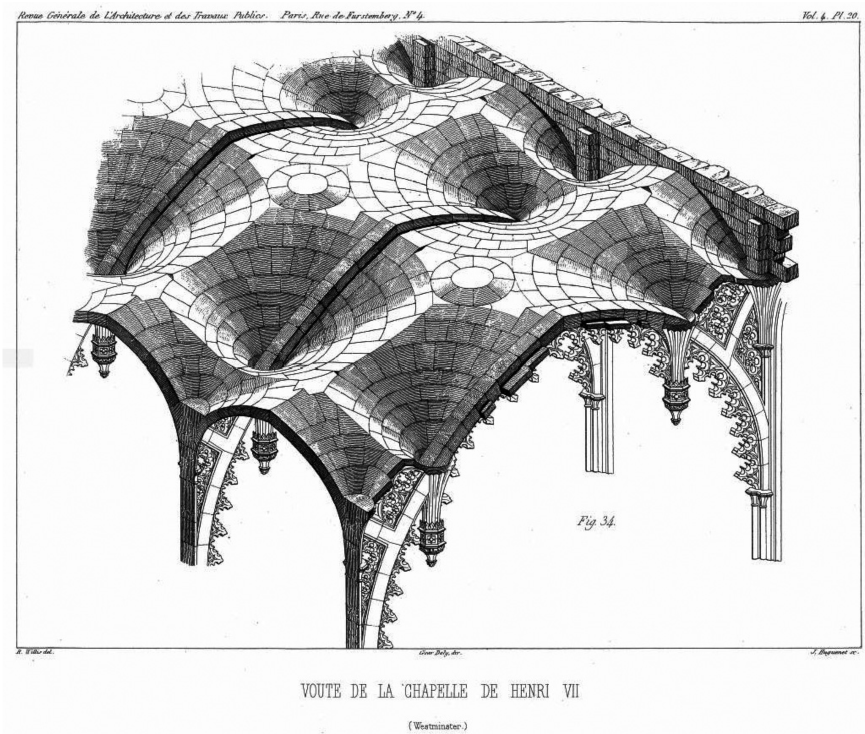


Figura 4
Tavola di Willis pubblicata da César Daly (Willis 1843, plate 20)

sempre ed unicamente al saggio in francese pubblicato sulla *R.G.A.T.P.* (Quicherat 1885–86, 266, 269).

Tra i rari studiosi che erano a conoscenza dei lavori di Willis e che li hanno considerati meritevoli di attenzione o comunque degni di figurare come testi di riferimento, va menzionato Jules Gailhabaud, fondatore nel 1844 della *Revue archéologique*. Autore di pubblicazioni che intendevano raccontare la storia dell'architettura attraverso le immagini, Gailhabaud ha citato in diverse occasioni i saggi sulle cattedrali inglesi —all'interno del suo libro *Monuments anciens et modernes* stampato in 4 volumi tra il 1840 e il 1850— e inserendo, tra l'altro, nella scheda bibliografica relativa a San Miniato il riferimento a *Remarks* (Gailhabaud 1850, II: np.).

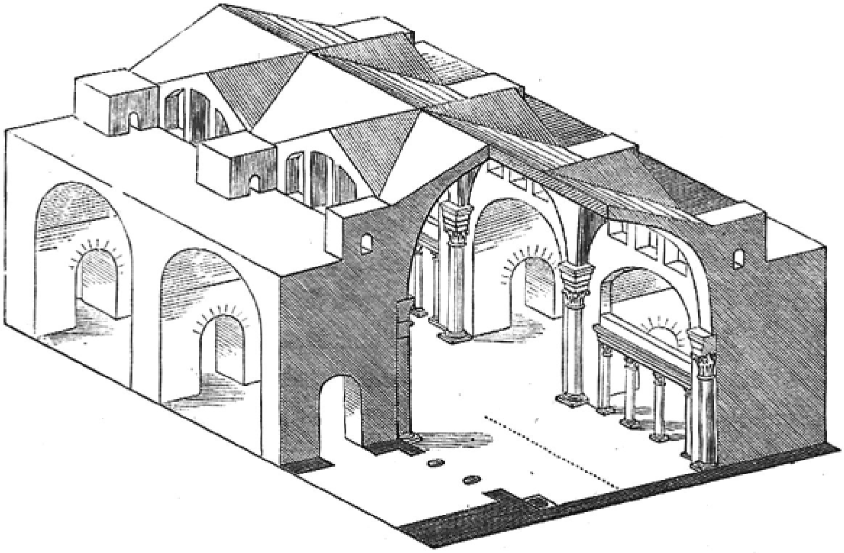
Nel corso della seconda metà dell'Ottocento risulta sempre più difficile trovare storici o archeologi che abbiano richiamato l'attenzione sugli studi del professore di Cambridge, come se la sua timida fama si fosse già completamente

eclissata. Che si tratti di opere di divulgazione come il testo di Corroyer del 1891 *L'Architecture gothique* (Corroyer 1891) o di lavori frutto di studi approfonditi da parte di archeologi come l'*Introduction de l'Architecture gothique en Italie par les cisterciens français* di Adolphe Dion (1891) o *L'Architecture religieuse en France à l'époque gothique* di Robert De Lasteyrie, pubblicato postumo ad opera di Marcel Aubert nel 1926–27, i riferimenti a Willis erano sempre assenti , mentre si preferiva rinviare ai lavori più recenti sulle origini del gotico redatti da John Bilson —menzionato da Aubert nel libro di Lasteyrie— o dal tedesco Oscar Mothes— citato a più riprese da Dion.

Una certa ambiguità nei confronti di Willis è invece dimostrata dal Daniel Ramée. Se, come abbiamo visto, l'architetto francese non ha ritenuto la *Nomenclature* un lavoro di riferimento per il suo *Dictionnaire*, non ha però esitato a riferirsi allo studioso inglese quando si è trattato di redigere la sua voluminosa *Histoire de l'architecture* (Ramée 1860–1885). Poliglotta (figlio di una tedesca e con un'ottima conoscenza dell'inglese e dell'italiano), Ramée ha dimostrato, soprattutto nei primi anni della sua carriera e fino al 1850 circa, un vivo interesse nei confronti del Medioevo, attestato dalla pubblicazione, nel 1843, di *Le Moyen-âge monumental et archéologique. Introduction générale* dove sosteneva che i tre testi didattici di riferimento erano costituiti dal libro di Rickman, da quello di Stieglitz e dall'opera di Caumont (Ramée 1843, 24) Anche nella sua *Histoire générale de l'architecture*, pubblicata in 3 volumi tra il 1860 e il 1885 (Ramée 1860–1885), il XIII secolo continuava ad occupare un posto di rilievo (Hamon e Rodriguez, 2009). Nel capitolo sui monumenti anglo-normanni all'interno del secondo volume edito nel 1862, Ramée ha citato la monografia della cattedrale di Canterbury di Willis, come fonte bibliografica di riferimento per l'attribuzione della costruzione del grande monumento religioso all'architetto Guillaume de Sens (Ramée 1860–85, 2: 1066). Willis figurava, assieme ad altri storici britannici, in quanto autore che aveva studiato l'origine dell'ogiva (Ramée, 1860–85, 2: 843). Poi, però, nel capitolo sull'Inghilterra dedicato allo "Style ogival" (Ramée, 1860–85, 2: 1071), Ramée ha preferito rimandare il lettore al lavoro di classificazione dell'architettura britannica pubblicato nel 1851 da Edmund Sharpe *The seven periods of English architecture defined and illustrated* (Sharpe 1851). D'altra parte, le immagini che ha utilizzato Ramée avevano una tutt'altra valenza rispetto ai disegni rigorosi, geometrici e strutturali di Willis. La volta della cappella di Henry VII all'interno della chiesa di Westminster, per esempio, veniva rappresentata attraverso un'illustrazione molto tradizionale che intendeva mettere in evidenza solo la ricchezza ornamentale della volta a ventaglio tipica dello stile perpendicolare (Ramée 1860–85, 2: 1073). L'approccio strutturale di Willis, particolarmente esplicito nello studio delle volte del 1842, era profondamente lontano dall'analisi descrittiva ed enumerativa che caratterizzava il lavoro di Ra-

mée il quale poteva avere qualche affinità solo con la pubblicazione del collega inglese del 1835. Il libro *Remarks* figurava infatti all'interno della bibliografia elaborata dallo storico francese in merito all'architettura italiana (Ramée, 1860–85, 2: 1084): la logica topografica e di catalogazione sottesa al primo lavoro che Willis aveva dato alle stampe, era più in sintonia con la mentalità di Ramée, piuttosto che le interpretazioni tecnico-costruttive. Un'eccezione è costituita dalla presenza nell'*Histoire générale* (Ramée, 1860–85, 2: 838) della rappresentazione isometrica delle terme romane elaborata e pubblicata da Willis nel 1835 (Willis 1835, plate 1). Ramée non ha menzionato la fonte né l'autore del disegno, ma ha ripreso l'interpretazione dello studioso inglese riguardo la nascita della cattedrale gotica. Al fine di spiegare l'origine delle volte medievali, l'architetto francese ha utilizzato lo schizzo isometrico delle terme spiegando nella didascalia, così come aveva fatto Willis, che all'edificio era stata tolta l'ornamentazione al fine di fare "comprendere l'origine di un certo numero di parti delle chiese del medioevo, come navate, collaterali, claristorio, triforio, archi rampanti, ecc." (Ramée, 1860–85, 2: 838). Ma se per lo studioso inglese quell'isometria doveva servire anche a capire meglio il rapporto tra esterno ed interno dell'edificio —così come esplicitamente espresso da Willis nella didascalia "to show the relation of the interior to the exterior" (Willis, 1835, 189)— per l'autore francese (seppur sedotto da questa immagine innovativa), esso era invece solo dimostrativo del ruolo precursore dell'architettura romana rispetto a quella medievale. Nessun valore spaziale, nessuna accentuazione della logica costruttiva e del suo legame con l'involucro venivano messi in evidenza da Ramée.

Il risultato più evidente e incontestabile dell'influsso dello studioso britannico in Francia è proprio legato alle rappresentazioni isometriche disegnate da Willis, anche se non è sempre chiara la logica con la quale gli autori francesi hanno ripreso, fin dagli anni quaranta dell'Ottocento, gli elaborati grafici riguardanti le volte delle cattedrali britanniche.[3] Uno dei primi ad aver riutilizzato le isometrie del professore di Cambridge è l'architetto Abel Blouet, il quale, nel supplemento al *Traité théorique et pratique de l'art de bâtir de Jean Rondelet* del 1847–48, ha pubblicato un paio di disegni delle cattedrali inglesi, senza tuttavia menzionarne l'autore né l'origine (Blouet 1847, plates IX–X). Oltre a Viollet-le-Duc che nell'articolo "Voûte" del *Dictionnaire raisonné* ha riprodotto con piccole modifiche lo spaccato isometrico della volta della cappella di Windsor (Viollet-le-Duc 1854–68, III: 536), anche Paul Planat ha illustrato la voce "Anglaise (Architecture)" della sua *Encyclopédie de l'architecture*, (Planat 1888–92, 171), con l'isometria della cattedrale di Peterborough (ancora una volta senza citare la fonte). La stessa immagine priva di copyright è apparsa anche in una pubblicazione accademica di prestigio come gli *Eléments et théorie de l'architecture* di Julien Guadet (Guadet 1901–04, 3: 169) il quale ha ripreso esattamente



302. — Esquisse isométrique des grandes salles des Thermes romains dépouillées de leur ornementation et faisant comprendre l'origine d'un certain nombre de parties des églises du moyen âge, telles que nefs, collatéraux, claire-voie, triforium, arcs-boutants, etc.

Figura 5
Schizzo isometrico delle terme romane : Ramée, Daniel. 1860–1885. *Histoire générale de l'architecture*. Paris: Amyot, 2 (1862) : 838.

l'impaginazione di Planat dove la cappella del King's College figurava accanto alla volta di Peterborough. Il celebre professore della École des Beaux-Arts, non si è però limitato ad utilizzare l'isometria di Willis ma, affrontando il tema delle volte, sembra che anche lui si sia ispirato all'interpretazione avanzata dallo studioso britannico sull'origine dell'ogiva basata su una concezione evoluzionistica dell'architettura. Si legge infatti: "En effet, les plus anciennes églises, vous le savez, *s'inspirant* de la tradition romaine des salles des termes… " (Guadet, 1901–04, 3: 353), o ancora "…on peut dire qu'une esquisse identique peut, suivant l'étude, aboutir soit à la travée de la salle des thermes de Caracalla, soit à la travée de la cathédrale d'Amiens" (Guadet, 1901–04, 2 :614).

Numerosi sono stati dunque gli architetti del XIX secolo che nelle loro pubblicazioni hanno riprodotto le immagini isometriche di Willis. Immagini che spesso erano accostate a disegni di natura completamente differente e di cui gli autori raramente coglievano le peculiarità e le potenzialità espressive. L'unico vero ed esplicito ammiratore —oltre a Viollet-le-Duc sul quale non abbiamo voluta-

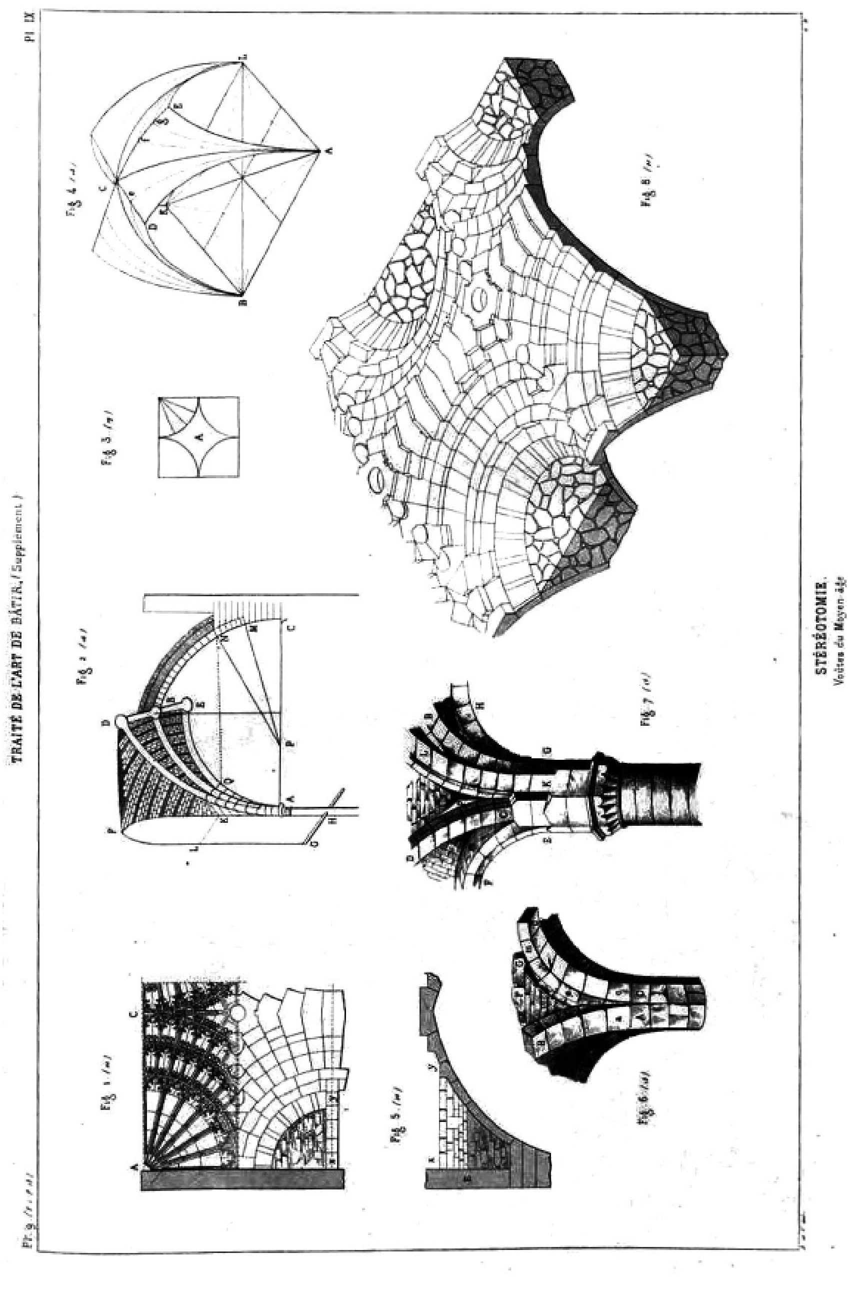


Figura 6
Volte medievali : Blouet, Abel, 1847–1848. *Traité théorique et pratique de l'art de bâtir de Jean Rondelet. Supplément de G.-Abel Blouet*. (Paris: Didot, plate IX)

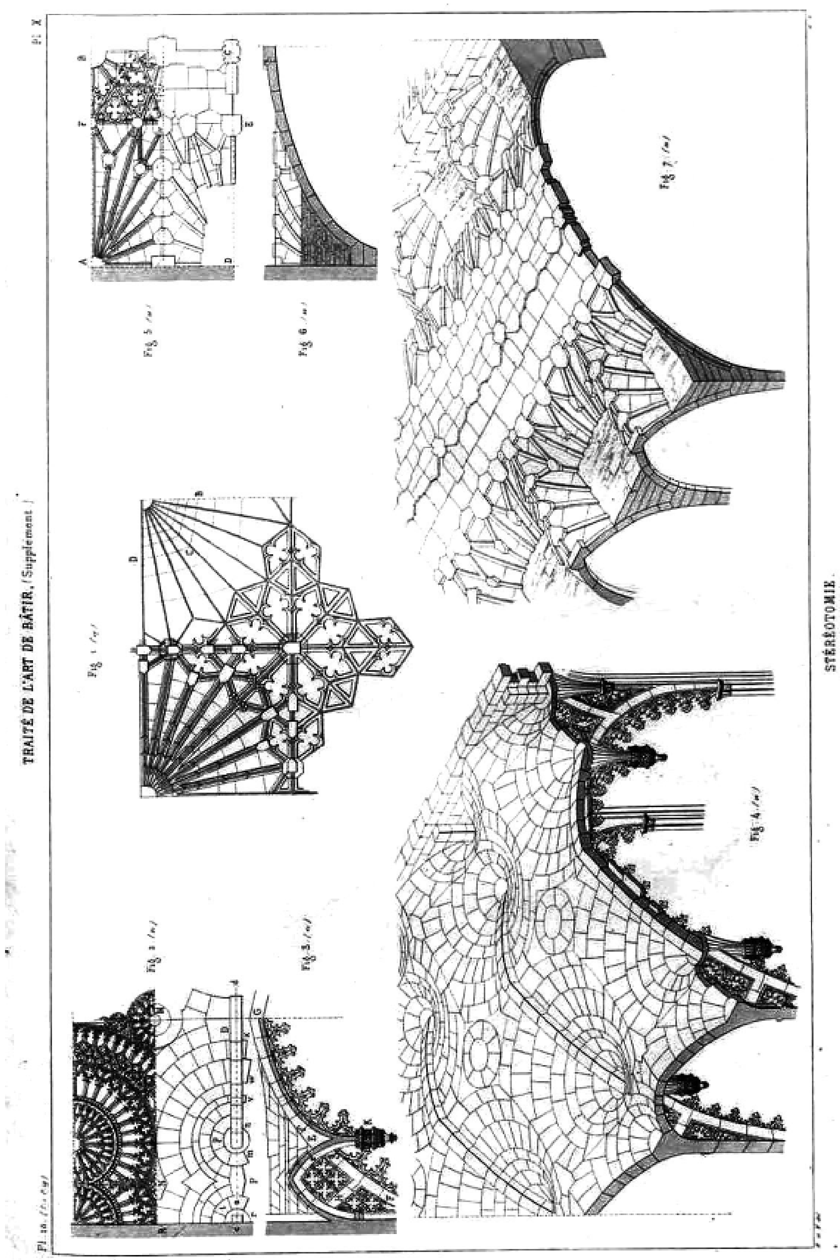


Figura 7
Volte medievali : Blouet, Abel, 1847–1848. *Traité théorique et pratique de l'art de bâtir de Jean Rondelet. Supplément de G.-Abel Blouet*. (Paris: Didot, plate X)

bien que l'étude de l'architecture fût laissée aux soins du personnel du bureau ; tel morceau

Fig. 30. — Chapiteau à Westminster.

important est évidemment l'œuvre de l'employé le plus fort, un dessinateur français très-probablement ; telle autre partie est laissée aux

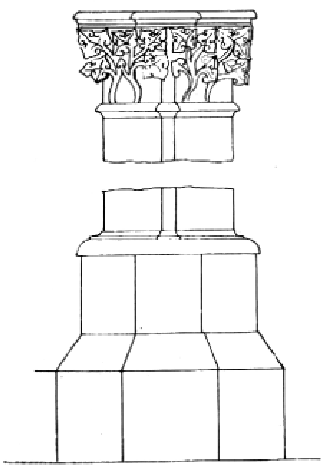


Fig. 31. — Eglise d'Howden.

soins d'un aide moins habile, d'un garçon de bureau peut-être, tant c'est mauvais ! Je sais bien que je ne puis appuyer mes allégations sur aucun document écrit, mais Wren nous a laissé une foule de documents en pierre que tout architecte qui sait son métier peut facilement interpréter. Pour ma part, j'y lis que le fort en architecture du bureau Wren était non seulement un Français, mais encore un élève de Mansard. C'est à lui que revient le mérite de toute l'architecture extérieure de la cathédrale de Saint-Paul (Fig. 41). Quant à l'intérieur, il s'est tiré d'affaire dans la nef où les données étaient à peu près les mêmes que celles des églises de Mansard, mais le plan Wren pour la coupole le désarçonna. Il est impossible de voir où que ce soit un plus horrible gâchis que l'architectore des arcades intérieures qui

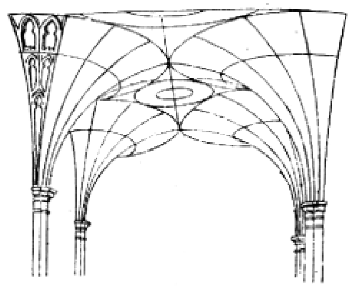


Fig. 32. — Chapelle du King's College

portent la coupole de Saint-Paul. C'est là que l'employé de Wren a prouvé qu'il n'était qu'un élève et non pas un génie créateur.

Une nouvelle révolution (1689) chassa la famille des Stuarts ; mais cette révolution paisible n'affecta pas le développement de l'ar-

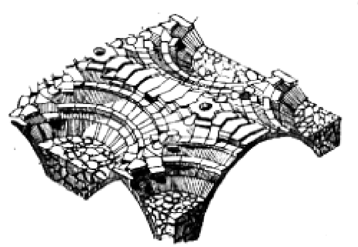


Fig. 33. — Cathédrale de Peterborough.

chitecture en Angleterre. L'architecture classique rentrée en Angleterre avec Wren resta, jusqu'à il y a environ 50 ans, l'architecture par excellence des demeures seigneuriales

Figura 8
Encyclopédie Planat, Paul eds. 1888–1892. *Encyclopédie de l'architecture*. (Paris: Bibliothèque de la Construction moderne, voce "Anglaise (Architecture)", 1: 171)

que figurée par un ravalement après coup. Mais l'aspect en est mou, on peut dire émoussé, et cette combinaison reste moins saisissable que la voûte fidèle à ses grands arcs diagonaux.

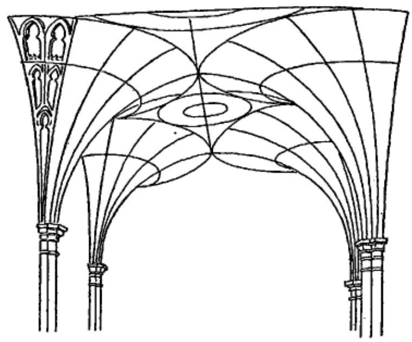


Fig. 1056. — Voûte de la chapelle de King's Collège. (Angleterre.)

Mais quelles que soient vos préférences entre ces habiletés, nous sommes loin, vous le voyez, du jugement dédaigneux de Quatremère de Quincy et de sa « batisse ignorante »; au contraire, le défaut de cette architecture serait plutôt dans l'excès d'habileté, car l'habileté appelle le tour de force, et c'est le tour de force qui lui deviendra fatal — en effet, par une loi vraiment morale et constante, le tour de force est un des symptômes les plus certains de la décadence ou tout au moins de son approche. Mais à sa plus belle époque même, l'habileté est bien remarquable, et était bien nécessaire pour la mise en œuvre de cette architecture.

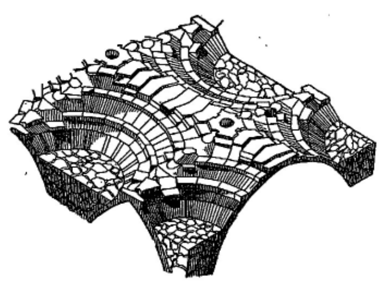


Fig. 1057. — Voûte de la cathédrale de Péterboroug (Angleterre).

Je vous ai montré comment l'architecture des Romains, non moins économe dans l'acception élevée du mot, était admirablement combinée pour une société où le manœuvre, le prisonnier de guerre qui n'avait que ses bras sans habileté, pouvait trouver en très grand nombre un travail à sa portée, sous la conduite d'un nombre relative-

Figura 9
Volta della cattedrale di Peterborough: Guadet, Julien. 1901–1904. *Eléments et théorie de l'architecture, cours professé à l'École Nationale et spéciale des beaux-arts* (Paris: Aulanier, 3: 169)

mente insistito— che ha rivendicato chiaramente il ruolo di Willis nel suo operato e nel suo sistema iconografico è stato Auguste Choisy (Mandoul 2008). L'ingegnere francese ha colto le specificità cognitive, espressive e spaziali del metodo di rappresentazione grafico dello studioso inglese. L'astrazione delle assonometrie di Choisy e l'eliminazione di ogni dettaglio ornamentale dai suoi elaborati grafici —visto che l'ingegnere riteneva, contrariamente a Viollet-le-Duc, che l'ornamento fosse applicato sopra la struttura e non fosse una parte essenziale dell'edificio— rivelavano le contaminazioni e le assonanze che lo studioso francese ha riconosciuto pubblicamente. In occasione del ricevimento della medaglia d'oro da parte della Corona britannica nel 1904, Choisy ha infatti dichiarato: "Presque enfant, feuilletant les livres de la bibliothèque de mon père, j'eus la bonne fortune de rencontrer le Mémoire du Révérend Robert Willis sur les voûtes du Moyen Age. Ce fut une révélation: C'est ainsi, me dis-je, que les formes doivent être analysées ; c'est ainsi que le dessin doit exprimer la structure. Et, lorsque j'essayais de résumer les procédés romains, j'eus sans cesse présent comme un modèle de méthode ce mémoire sans précédent, qui marque à la fois les débuts et le dernier terme de la critique architecturale".[4]

L'esplicita affermazione di stima nei confronti dei disegni elaborati da Willis da parte di colui che ha impiegato sistematicamente gli spaccati assonometrici nelle sue pubblicazioni, costituisce quindi un'eccezione nel panorama della letteratura architettonica francese. L'influenza del professore inglese non solo è stata ridotta e timida, ma come abbiamo visto, anche quasi mai dichiarata. Le sue isometrie sono state depredate dalla storiografia francese senza mai rendere al suo autore il giusto tributo, così come è avvenuto per la teoria evoluzionistica di Willis e per le sue ipotesi sull'origine delle volte gotiche. Si potrebbe ipotizzare che l'analisi delle tecniche costruttive abbia avuto un impatto poco evidente in Francia, proprio perché il paese aveva da sempre rivolto uno sguardo razionale all'architettura medievale e che pertanto l'apporto di Willis non fosse considerato così innovativo. Resta da capire se l'approccio definito "membrologico" da Frankl (Frankl 1960 ; Buchanan 2013) abbia avuto una ricaduta più tangibile sulla metodogia impiegata dagli autori francesi di inizio Novecento. La struttura dei corsi sull'architettura medievale tenuti dall'archeologo Marcel Aubert alla École des Beaux-Arts nel corso degli anni Trenta del XX secolo,[5] potrebbe far pensare agli studi e alle pubblicazioni di Willis. Le lezioni strutturate per temi costruttivi (volte, coperture ecc.) nonché le diverse conferenze e saggi di Aubert sulle origini delle volte ogivali,[6] sembravano echeggiare gli interessi e l'approccio del reverendo inglese, anche se si persisteva a non menzionarne il nome. L'organizzazione e la struttura delle monografie sulle cattedrali redatte dal professore di Cambridge, meriterebbero anch'esse un'indagine approfondita al fine di capire quanto la storiografia francese otto-novecentesca sia stata debitrice nei

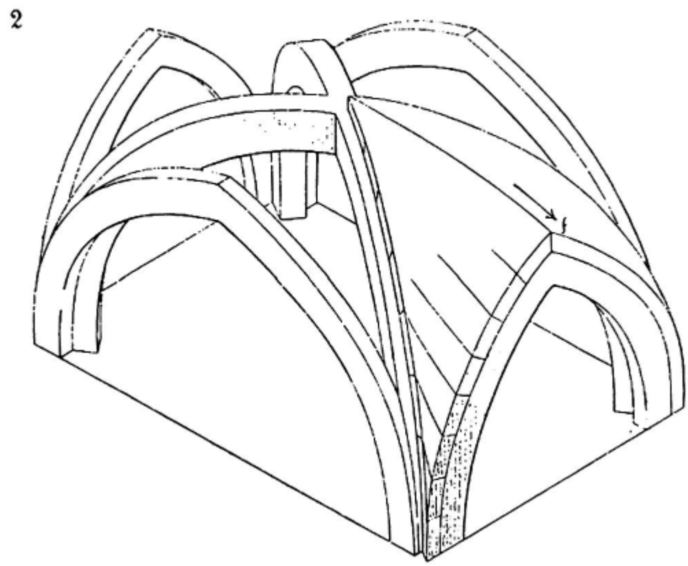


Figura 10
Volta gotica: Choisy, Auguste. 1899. *Histoire de l'architecture* (Paris: Gauthier-Villars, 2: 268)

confronti dell'autore britannico (Buchanan 2013). Il saggio pubblicato nel 1907 dall'archeologo Lefèvre-Pontalis dal titolo *Comment doit-on rédiger la monographie d'une église* (Lefèvre-Pontalis, 1907a) nonché l'articolo dato alle stampe nello stesso anno "Le plan d'une monographie d'église et le vocabulaire archéologique" (Lefèvre-Pontalis 1907b) meriterebbero di essere messi a confronto con la struttura delle monografie di Willis. L'autore inglese è stato ignorato dal direttore della Société Française d'Archéologie il quale non ha abbandonato la tradizione di fare rimandi unicamente a pubblicazioni nazionali. Solo nel 1913, scrivendo un testo sulle chiese romaniche benedettine, Lefèvre-Pontalis ha rinviato ad una pubblicazione di Willis, ma per un tutt'altro aspetto, ovvero per ricordare il ruolo di Willis negli scavi effettuati presso la cattedrale di Ely (Lefèvre-Pontalis 1913, 25).[7] Al di là delle preziose informazioni storiche e artistiche fornite dalle monografie di Willis —informazioni che hanno condotto autori come Ruprich-Robert ad inserire nella bibliografia di "L'Architecture normande" i testi del professore inglese e in particolare le pubblicazioni sulle cattedrali di Winchester, di Chester e sulla città di York (Ruprich-Robert 1889)— è lecito chiedersi quanto la metodologia storica, l'indagine analitica e la struttura espositiva delle monografie redatte dal professore di Cambridge abbiano real-

COMMENT DOIT-ON RÉDIGER

LA

MONOGRAPHIE D'UNE ÉGLISE?

PAR

Eugène LEFÈVRE-PONTALIS,

DIRECTEUR DE LA SOCIÉTÉ FRANÇAISE D'ARCHÉOLOGIE,
MEMBRE DU COMITÉ DES TRAVAUX HISTORIQUES
ET DE LA SOCIÉTÉ DES ANTIQUAIRES DE FRANCE.

CAEN
HENRI DELESQUES, IMPRIMEUR-ÉDITEUR
34, RUE DEMOLOMBE, 34

1907

Figura 11
Frontespizio di Lefèvre Lefèvre-Pontalis, Eugène. 1907. *Comment doit-on rédiger la monographie d'une église*. (Caen : Deleques)

mente influenzato la cultura architettonica francese. Ma così come la fortuna critica di Willis è stata stentata e la ricezione della sua opera nei paesi latini (Italia e Francia) limitata, così anche questo saggio non ha pretese di andare oltre ad una timida e velata indagine esplorativa, scevra da qualunque obiettivo di esaustività. Molte piste rimangono infatti aperte: piste che potranno permettere di scoprire, eventualmente, che l'influenza di Willis in questi paesi sia stata, seppur fulminea e quasi mai dichiarata, più importante e più forte di quello che fino ad ora è stato messo in evidenza.

Note

1. Numerosi sono i testi francesi citati, tutti rigorosamente in lingua originale. Anche i titoli dei libri tedeschi non sono tradotti, contrariamente a quelli inglesi che sono indicati con un titolo tradotto in italiano. E' possibile che questa disparità derivasse dalle conoscenze linguistiche di Pietro Selvatico, che sappiamo aver compiuto un viaggio in Germania nel 1844, pubblicando, al suo ritorno lo *Scritto sull'arte tedesca*.
2. Arcisse de Caumont aveva conosciuto Rickman a Caen nel 1832 (Pevsner 1972).
3. Tali immagini erano state riprodotte, lo ricordiamo ancora una volta, da Daly nel 1843 nella R.G.A. (Willis 1843).
4. Tali considerazioni si trovano nella risposta di A. Choisy pubblicata in : A. Webb, "Remise de la médaille d'or du Roi d'Angleterre le 20 juin 1904 à M. Auguste Choisy", *Annales des ponts et chaussées*, t. 4, 1904, pp. 211–218 (n. 47). Le texte est cité par Thierry Mandoul (Mandoul 2008, 129–130).
5. Il fondo di Marcel Aubert è conservato a Parigi presso l'Institut National d'Histoire de l'Art.
6. La conferenza tenuta a Londra nel 1931 aveva come titolo "Les origines de la voûte sur croisée d'ogives". La pubblicazione del 1934 era dedicata a *Les plus anciennes croisées d'ogives, leur rôle dans la construction* (Paris: Picard).
7. Nella pubblicazione di Lefèvre-Pontalis del 1913 dal titolo *Les plans des églises romanes bénédictines*, l'autore menzionava Willis come autore degli scavi effettuati nella cattedrale di Ely (Lefèvre-Pontalis 1913, 25).

Riferimenti bibliografici

Batissier, Louis. 1843. *Eléments d'archéologie nationale, précédés d'une histoire de l'art monumental chez les anciens*. Paris: Leleux.

Batissier, Louis. 1845. *Histoire de l'art monumental dans l'antiquité et au Moyen Age. Suivi d'un traité de la peinture sur verre*. Paris: Furne.

Bernabei, Franco. 1974. *Pietro Selvatico nella critica e nella storia delle arti figurative dell'Ottocento*. Vicenza: Neri Pozzi.

Berty, Adolphe. 1845. *Dictionnaire de l'architecture du moyen âge, contenant tous les termes techniques dont l'intelligence est nécessaire pour faire ou comprendre les descriptions des monuments religieux, civils et militaires*. Paris: Derache.

Blouet, Abel, 1847–1848. *Traité théorique et pratique de l'art de bâtir de Jean Rondelet. Supplément de G.-Abel Blouet*. Paris: Didot.

Boid, Edward. 1829. *A concise history and analysis of all the principal styles of architecture, by an amateur*. London: Cadell.

Boito, Camillo. 1880. *Architettura del Medio Evo in Italia: con una introduzione sullo stile futuro dell'architettura italiana*. Milano: Hoepli.

Buchanan, Alexandrina. 2013. *Robert Willis (1800–1875) and the Foundation of Architectural History*. Woodbridge: The Boydell Press.

Caumont, Arcisse De. 1836. *Histoire sommaire de l'architecture religieuse, militaire et civile au moyen âge*. Caen: Hardel.

Caumont, Arcisse De. 1830–1835. *Cours d'antiquités monumentales professé à Caen par M. de Caumont. Histoire de l'art dans l'Ouest de la France.* Paris : Caen.

Caumont, Arcisse De. 1846. *Définition élémentaire de quelques termes d'architecture*. Paris: Derache-Dumoulin.

Chabat, Pierre. 1875–1878. *Dictionnaire des termes employés dans la construction et concernant la connaissance et l'emploi des matériaux, l'outillage qui sert à leur mise en œuvre, l'utilisation de ces matériaux dans la construction des divers genres d'édifices anciens et modernes, la législation des bâtiments*. Paris: s.n.

Chiovelli, Renzo. 2007. *Tecniche costruttive murarie medievali: la Tuscia*. Roma: L'Erma di Bretschneider.

Choisy, Auguste. 1899. *Histoire de l'architecture*. Paris: Gauthier-Villars.

Corroyer, Edouard. 1891. *L'architecture gothique*. Paris: Quantin.

De Stefani, Lorenzo. 1992. *Le scuole di architettura in Italia. Il dibattito dal 1860 al 1933*. Milano: Franco Angeli.

Di Pasquale, Salvatore. 1996. *L'arte del costruire. Tra conoscenza e scienza*. Venezia: Marsilio.

Dion, Adolphe. 1891. *Introduction de l'Architecture gothique en Italie par les cisterciens français*. Caen: Delesque.

Enlart, Camille. 1894. *Origines françaises de l'architecture gothique en Italie*. Paris: Thorin et fils.

Forty, Adrian. [2000] 2004. *Parole e edifici. Un vocabolario per l'architettura moderna*. Bologna: Pendragon.

Frankl, Paul. 1960. *The gothic: literary sources and interpretations through eight centuries.* Princeton: Princeton University press.

Gailhabaud, Jules. 1850. *Monuments anciens et modernes. Collection formant une histoire de l'architecture des différents peuples à toutes les époques*. Paris: Didot.

Giovannoni, Gustavo. 1925. *La tecnica della costruzione presso i romani*. Roma: Società editrice d'arte illustrata.

Guadet, Julien. 1901–1904. *Eléments et théorie de l'architecture, cours professé à l'École Nationale et spéciale des beaux-arts*. Paris: Aulanier.

Hamon, Françoise and Rodriguez, Peggy. 2009. Daniel Ramée. In *Dictionnaire critique des historiens de l'art actifs en France de la Révolution à la Première Guerre mondiale,* edited by P. Sénéchal and C. Barbillon. Paris: INHA (digital resource).

Hope, Thomas. 1835. *An historical essay on architecture, illustrated by drawings*. London: Murray.

Huerta, Santiago. 2009. The Debate about the Structural Behaviour of Gothic Vaults: From Viollet-le-Duc to Heyman. In *Proceedings of the Third International Congress on Construction History* edited by K.E Kurrer, W. Lorenz, W. Wetzk, 837–844. Berlin: Neunplus1.

Kidson, Peter. 1996. Gotico. In *Enciclopedia dell'arte medievale*, VII, 41–54. Roma: Treccani.

Kruft, Hanno-Walter. 1989. La théorie de l'architecture gothique énoncée par le XIXe siècle. In *Les batisseurs des cathédrales gothiques* edited by R. Recht, 309–321. Strasbourg: Éditions les Musées de la Ville de Strasbourg.

Lasteyrie Du Saillant, Robert. 1926–1927. *L'Architecture religieuse en France à l'époque gothique*, edited by M. Aubert. Paris: Picard.

Lefèvre-Pontalis, Eugène. 1907a. *Comment doit-on rédiger la monographie d'une église*. Caen : Deleques.

Lefèvre-Pontalis, Eugène. 1907b. Le plan d'une monographie d'église et le vocabulaire archéologique. *Bulletin monumental*. 71, 136–159.

Lefèvre-Pontalis, Eugène. 1913. *Les plans des églises romanes bénédictines*. Caen: Delesques.

Magister Comacino. 1858. Sull'architettura in stile lombardo. *Giornale dell'Ingegnere, Architetto e Agronomo*. 7, 149.

Mandoul, Thierry. 2008. *Entre raison et utopie, L'Histoire de l'Architecture d'Auguste Choisy*. Wavre: Mardaga.

Marchis, Vittorio. 2002. Giulio Carlo Ignazio. In *Dizionario biografico degli Italiani*, LVII, 52–54. Roma: Istituto della Enciclopedia Italiana.

Marchis, Vittorio. 2006. Dall'ingegneria come pratica all'ingegneria come scienza. In *La storia dell'ingegneria e degli studi di ingegneria a Palermo e in Italia*, edited by V. Cardone, Vito, F. P. La Mantia, 53–104. Salerno: Cues.

Milani, Giovanni Battista. 1920. *L'ossatura murale: Studio statico-costruttivo ed estetico-proporzionale degli organismi architettonici, con Speciale riferimento alle strutture elastiche nelle loro varie moderne applicazioni pratiche*. Torino: Soc. Italiana di Edizioni Artistiche, C. Crudo e C.

Muggia, Attilio. 1893–1894. *Lezioni di Architettura tecnica esposte dall'Ing. Attilio Muggia nel 1° corso della R. Scuola d'Applicazione per ingegneri*. Bologna: s.n.

Muggia, Attilio. 1933. *Storia dell'architettura. Dai primordi ai giorni nostri*. Milano: Vallardi.

Parker, Henry. 1836. *A Glossary of Terms used in Grecian, Roman, Italian, and Gothic Architecture*. London: Charles Tilt.

Patetta, Luciano. 1975. *L'architettura dell'eclettismo. Fonti, teorie, modelli. 1750–1900*. Milano: Mazzotta.

Pevsner, Nikolaus. 1972. *Some Architectural Writers of the Nineteenth Century*. Oxford: Clarendon Press.

Planat, Paul eds. 1888–1892. *Encyclopédie de l'architecture*. Paris: Bibliothèque de la Construction moderne.

Quicherat, Jules. 1885–1886. *Mélanges d'archéologie et d'histoire*. Paris: Picard.

Ramée, Daniel. 1843. *Le Moyen-âge monumental et archéologique. Introduction générale*. Paris: Hauser.

Ramée, Daniel. 1860–1885. *Histoire générale de l'architecture*. Paris: Amyot.

Ramée, Daniel. 1868. *Dictionnaire général des termes d'architecture en français, allemand, anglais et italien*. Paris: Reinwald.

Ricci, Amico. 1857–1859. *Storia dell'architettura in Italia: dal secolo 4. al 18*. Modena: Regio-Ducal Camera.

Ricci, Giuliana eds. 1992. *L'architettura nelle Accademie riformate. Insegnamento, dibattito culturale, interventi pubblici*. Milano: Guerini.

Rickman, Thomas. 1815. *An Attempt to Discriminate the Styles of Architecture in England*. Liverpool: Panorama of Science and Art.

Ruprich-Robert, Victor. 1889. *L'Architecture normande aux XIe et XIIe siècles en Normandie et en Angleterre*. Paris: Librairie des imprimeries réunies.

Saboya, Marc. 1991. *Presse et Architecture au XIX siècle*. Paris: Picard.

Sharpe, Edmund. 1851. *The seven periods of English architecture defined and illustrated*. London: Bell.

Selvatico, Pietro. 1847. *Sulla Architettura e sulla Scultura in Venezia dal Medio Evo sino ai nostri giorni*. Venezia:· Ripamonti Carpano.

Street, George E. 1855. *Brick and marble in the Middle Ages: Notes of a tour in the North Italy*. London: Murray.

Talenti, Simona. 2011. Architetti e studiosi francesi per l'architettura dei "primitivi" toscani. *Bollettino Della Società Di Studi Fiorentini*. 20, 290–297.

Talenti, Simona. 2012. The Italian Engineers' Architecture and Technique Training. In *Nuts and Bolts of Construction History. Culture, Technology and Society*, edited by R. Carvé, A. Guillerme, V. Nègre, J. Sakarovitch, 587–593. Paris: Picard.

Viollet-le-Duc, Eugène. 1854–1868. *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle*. Paris: Bance-Morel.

Willis, Robert, 1835. *Remarks of the Architecture of the Middle Ages, especially of Italy*. Cambridge: Deighton.

Willis, Robert. 1841. *Principles of Mechanism: designed for the use of students in the universities and for engineering students generally*. London: Parker.

Willis, Robert. 1842. On the Construction of the Vaults of the Middle Ages. *Transactions of the Royal Institute of British Architects*, 1: l–69.

Willis, Robert. 1843. Mémoire de Monsieur Willis sur la construction des voûtes au Moyen Age, traduit de l'anglais par Monsieur César Daly. *Revue Générale de l'Architecture et des Travaux Publics*, IV : 3–14; 289–304; 481–507.

Willis, Robert. 1844. *Architectural Nomenclature of the Middle Ages.* Cambridge: Deighton & Stevenson.

Robert Willis and Germany: Gothic Revival and research on Mediaeval Architecture

David Wendland

In short,[1] the Gothic Revival in Germany in the first decades of the 19th century has two sides. One is the romantic idea of recreating a link to the idealized Middle Ages, which is additionally charged with the national self-discovery in and after the Napoleonic occupation. The other side is the idea of creating a new architecture in which form, construction and structure would be intrinsically linked —an idea which by the middle of the century could be successfully implemented into the academic formation of architects, for instance, by Georg Gottlieb Ungewitter and, of course, through the writings of his mentor Viollet-le-Duc. But the basis was laid by architects and scholars from the previous generation, in particular in the years from 1820 on— it was the beginning of the Modern Movement in architecture.

British influence had a key role on both of these aspects. On one hand, Horace Walpole's Strawberry Hill triggered the creation of several buildings in medieval style in Germany, such as the "Gothic House" in the park of Wörlitz, 1786/87, and the octagonal tower Freiherr vom Stein had built from 1814 to 1827 in his palace at Nassau, dedicated to the memory of the Liberation. As for the other side, there is the impact of writings from British scholars who made historical architecture a subject of rigorous scientific research, and who systematically analyzed how these buildings were designed and constructed —for instance, Thomas Rickman, William Whewell, and, in particular for the latter, Robert Willis.

In Germany, all this fell into good ground. The architectural environment was marked by buildings in Gothic style, which for instance persisted in most of the

parish churches in spite of later furnishing —hence, the buildings were not only there for being studied, but were also present in daily public and cultural life. In particular, there were the fascinating examples of the great cathedrals, which play a key role in the Gothic revival: So for instance, the cathedral of Strasbourg which inspired the young Goethe in 1773 to his hymn *Von Deutscher Baukunst,* dedicated to the great genius of the medieval master builder Erwin von Steinbach. Or the colossal fragment of the cathedral in Cologne, the completion of which became a collective effort of creating a monument of the German nation —and at the same time also became the most emblematic building project where medieval architecture was recreated.

Moreover, Gothic had never really ended. It would go far beyond our scope here to discuss the previous "Gothic revivals", in particular during the 17th century. Much more relevant for the recovery of design and construction in accordance to supposed medieval principles is the persistence of the late Gothic design practice in the teaching of stonemasons and architects. For instance, it is known that in Nuremberg every master builder at the end of his formation had to deliver a master piece which consisted in the design of a church choir in Gothic style in drawings and models, where in particular the correct design of the rib vault had to be demonstrated. Hence, among planners and craftsmen there seems to have always been some acquaintance with the geometric concepts and the procedures of setting-out in Gothic architecture, until the Napoleonic wars. Significantly, the last master builder to the city council of Nuremberg, Lorenz Kieskalt, in 1816 handed over his own masterpiece to Sulpiz Boisserée, who systematically studied late Gothic proportion systems when he worked out the reconstruction of the original design of Cologne cathedral (Wendland 2008, 120, 128). Model projects of this type, medieval drawings, as well as late Gothic and post-Gothic design treatises that give an insight to the medieval design practice, have early been studied by German scholars, in particular by Boisserée, Carl Alexander Heideloff and Johann Claudius von Lassaulx.

Robert Willis and Johann Claudius von Lassaulx

An important figure in the efforts of systematically studying medieval constructions, and of resuming the design and construction inspired on medieval architecture in practice, was Johann Claudius von Lassaulx (1781–1848). His work embraces a considerable oeuvre as architect and an intense activity in the publication of graphic prints and writings, as well as an astonishing scholarship on medieval architecture (Wendland 2008). And he is also an important link to the British scholarship in medieval architecture in the first decades of the 19th century.

Figure 1.
Parish Church at Treis, built by Lassaulx in 1824–31: Detail of the vault in the nave (Ventas / Wendland)

As an architect, Lassaulx was already involved in the construction of vom Stein's tower, mentioned above. His own projects include restorations of medieval structures as well as many new buildings, including several large parish churches. The church in Treis (Figure 1) in the vicinity of Koblenz shares the rank of being the first neo-Gothic church in Germany with Schinkel's Friedrichwerdersche Kirche in Berlin, built in the same years 1824–31. The design is based on historical examples and also on the scientific study of the mentioned sources on medieval design principles: Thus, going far beyond a compilation of features taken from historical examples, Lassaulx is able to make recourse to the "code" of medieval architecture, obtaining a remarkable philological quality in his design. He combines this with contemporary structural theory, highlighting also the central role of construction technique which is derived from the reception of medieval architecture and, as already pointed out, would become a core issue the architectural theory inspired by the Gothic Revival.

The project of the church in Treis was largely disseminated through publications by Lassaulx, as it was apt to demonstrate the practical feasibility of reproducing medieval architecture in modern building. Most important, the rib vaults in Gothic style provided the practical solution for the central feature of medieval church architecture, which is the construction of the vaults: Hence, the church in Treis can be considered as a prototype for the completion of the naves of Cologne cathedral and for any new construction of rib vaults in Gothic style. This is also underlined by Lassaulx's ground-breaking essay on vault construction, published 1829 in the first issue of the *Journal für die Baukunst*: "Instruction for the building of light-weight vaults over churches and similar spaces", where the principles of medieval vault design are described and a concise and practical description of how masonry vaults can be built without formwork is given (Wendland 2008, 86–95 and elsewhere). This text had great influence in the development of the technical literature, enjoyed international reception and is also cited as "excellent paper" by Robert Willis (1842a, 4 n.2).

At present, there is no documentary evidence that Lassaulx and Willis ever personally met, although Willis, according to the preface of his *Remarks,* in 1832/33 had also visited Germany (Willis 1835, a). He certainly would have enjoyed a visit to the church in Treis, as Lassaulx's design perfectly corresponds to Willis's appeal to "obtain the master key" and designing in accordance to the principles of medieval architecture instead of "merely *copying*" (Willis 1842a, 2, italics in original).

In any case, Lassaulx must have had early knowledge of Willis's work through his close contact to British scholars at his time, in particular William Whewell, who calls him "my valued friend". Lassaulx and Whewell corresponded and actually met at least once in Koblenz (Wendland 2008, 100). Whewell in-

cluded a text by Lassaulx in the third edition of his *Architectural Notes on German Churches*, "Architectural and historical remarks and additions" (Whewell 1842, 147–226), an English translation of a text previously published in 1835 as appendix to a travel guide —*Rheinreise* by Johann August Klein (one of the first books in the context of the Rhine romanticism and, by the way, the first travel guide published by Baedecker). Previously, Whewell had presented Lassaulx's ground-breaking essay on the construction of vaults without formwork in the *Journal of the Royal Institution* (Lassaulx 1831).

Robert Willis's research on mediaeval architecture had its first reception in Germany through Lassaulx's illustrated essay on the morphology of vaults, *Gewölbeformen*, where Lassaulx refers to, cites and explicitly praises some of Willis's writing. This essay had a rather high impact, as it appeared in 1846 in both major German architectural journals, *Zeitschrift für praktische Baukunst* and *Allgemeine Bauzeitung*; an extended and improved version was published in a short monograph in 1847. It reports presentations of his collection of models of vaults with didactic purpose, which Lassaulx gave in public lectures held in 1846 at the general assembly of architects and engineers in Gotha as well as at the Congrès Archéologique at Metz (Wendland 2008, 98). Lassaulx launched the distribution of reproductions of his models as teaching samples, but it is not clear whether he actually succeeded in this effort before his death in 1848.

The core of the essay consists in a series of drawings which are organized on one plate (Figure 2) —in the latest edition second plate with more figures is added— exposing the examples in clear isometric line drawings, along with some other instructive graphics like plans and elevations. After a short introduction, the numbered figures are explained one by one. It is a systematic vault morphology which is not based on style or ornamental features but solely on geometric and structural principles, and developed from the elementary concepts to the more complex solutions. The rather stringent essay is the summa of Lassaulx's considerations on the design and construction of vaults, including in an appendix also an essential recapitulation on the construction of vaults without formwork which Lassaulx had exposed in 1829. The graphical representation which shows the same remarkable clarity as the text, is based on the example of the vault drawings published by Samuel Ware (1814) cited by Lassaulx in other occasion —alike Plate II in Willis's *Remarks* (1835), but instead of the perspective Lassaulx uses isometric drawings, pointing out the advantages of such a representation. Based on "all forms of vaults which the author has come to know", Lassaulx attempts to show the development of the diversity of the shapes of vaults in a "natural consequence", which, as he states, apparently also roughly corresponds to the historical development (Lassaulx 1847, 1; our translation). The basic items of this development are the cylinder and the sphere, the parts of which

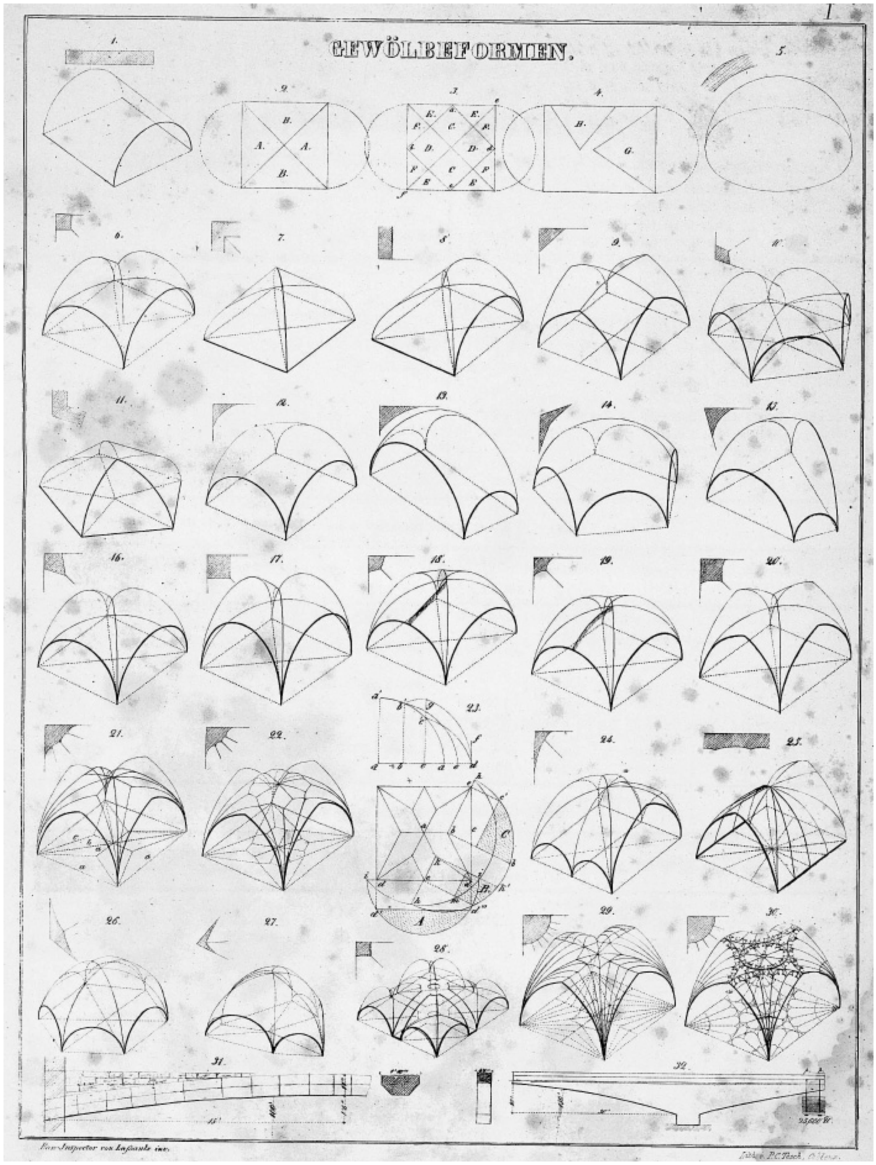


Figure 2.
Plate from Lassaulx's *Gewölbeformen* (1847, pl.1), showing the morphology of vaults. The representation of the horizontal section in double scale next to the isometric drawings is evidently inspired by Robert Willis's concept of the "middle plan".

are combined in multiple ways. It must be pointed out, however, that this is meant in a very broad conceptual sense: Lassaulx is far from just combining the surfaces of defined geometric bodies, knowing well that vaults can be also defined by the curves of the arches and groins, which in particular in the case of Gothic vaults constitute the primary feature of their geometric concept. Lassaulx is the first German speaking author who correctly explains the essential character of Gothic vaulting —already in 1829— and employs this knowledge also in the vaults built by him. The remarkable philological quality he achieves in his neo-mediaeval vaults, as we already pointed out, is basically due to the fact that he understood and correctly applied the geometric principles of Gothic vault design. These design principles are also discussed in *Gewölbeformen*, with reference to the available sources from the tradition of Gothic architectural design practise.

The 1846 edition of *Gewölbeformen* met a broad diffusion and was used and cited even decades later (Wendland 2008, 84); we find its impact, for instance, in important works such as Breymann's treatise on construction (Breymann 1849 and later editions) and Ungewitter's *Lehrbuch der gothischen Constructionen* (1859–1864), and it is received also in modern scholarly works.

Of Robert Willis, both the *Remarks on the Architecture of the Middle Ages* (1835) and the essay *On the construction of the vaults in the middle-ages* (1842a) are cited. For instance, Lassaulx refers to the description of domical vaults and the problem of double curved groins in cross vaults on rectangular plan, in the *Remarks*. Lassaulx refrains from showing this effect in a drawing, as he considers it a flaw which can be avoided with a strategy which is completely coherent with medieval vault design and especially with a straight-forward construction process (and therefore also represent the general practice). Namely, the different arches of the cross vault —the confining arches of the short and long side of the rectangular bay and the diagonal arch— can be easily defined as plane circle segments with different spans but the same fleche, which Lassaulx demonstrates by showing simply the elevation of these arches (1847, pl.2). Willis's essay on vault construction is directly cited in the section dedicated to fan vaults, where Lassaulx refers to it as "excellent essay on medieval vaulting, in particular on the English fan vaults, with the most complete illustrations" (Lassaulx 1847, 4, our translation). In this note, Lassaulx also mentions the German translation of Willis's essay in the *Zeitschrift für praktische Baukunst* (1842b), angrily criticizing the suppression of the author's name and accusing other examples of plagiaristic behaviour of that journal.

But a more general and even substantial influence of Willis's essay can also be seen in the graphics of *Gewölbeformen,* where next to every isometric drawing a horizontal section of the spandrel is shown in double scale: "As one can see, every one of these sections is different from the other, and any of these

vaults could be also denominated by this feature" (Lassaulx 1847, 1, our translation). These horizontal sections are explicitly located at the half of the total height, hence they correspond exactly to the "middle plan" which Willis introduces to understand the possible ways of controlling the curvature of the multiple rising ribs (e.g. 1842a, 19), and which leads him to the idea of considering the spandrel solid as a design criterion. Lassaulx doesn't follow him that far, which is surely also due to the fact that in the Gothic vaulting in the German speaking area usually the arches are defined by single circle segments, hence a procedure to define oval arches for the ribs would be of marginal importance. But in any case, the middle plan introduced by Willis definitely provides a good way to represent the spatial effect of the vault from the inside, as Lassaulx employs it, and may also help understanding the structural conditions in the abutment.

The definition and use of the middle plan can be seen as characteristic for the conceptual and inventive practical approach to the understanding of medieval vault design which Willis and Lassaulx have in common. Moreover, the interrelation of the works of Willis and Lassaulx shows the internationality of the Gothic revival in the first half of the 19th century, both as historical interest and as attempt to develop a new approach to architectural design and construction in the industrial age. In this last aspect, the pioneers of the Gothic revival, in particular the generation of Willis, Lassaulx and their fellow archaeologists and architects, laid the basis for what would become the Modern architecture.

The direct reception of Robert Willis, "On the construction of the vaults in the middle-ages," in Germany

Willis's essay on medieval vaults had a significant and lasting influence in Germany, although unfortunately it was not connected with his name. In fact, already in 1842 a German translation was published in the second volume of the journal *Zeitschrift für Praktische Baukunst*, edited by J. Andreas Romberg in Leipzig (Willis 1842b). However, neither the name of its author is given, nor the original publication is mentioned.

The text is a literal translation with very few omissions (for example, as we also learn from Lassaulx's angry note, the notes mentioning his essay on vault construction were also suppressed); no attempt is made to adapt the passages referring to the contemporary English bibliography, and the terminology is significantly different from the common use in the contemporary German technical literature. The illustrations are obviously re-drawn and come in four plates: apart from the reproduced original plates, also the smaller figures which in the original publication are inserted in the text are re-arranged and concentrated in additional plates.

Hence, the entire essay with all illustrations was promptly accessible in Germany, in a journal which was rather well distributed as we can state from its presence in numerous historical libraries. It is hard to tell to which extent the original publication also circulated in Germany; it was in any case much easier for the German reader to use the translated version than the original. Hence, apart from those having direct contact to British scholars, like Lassaulx, probably nearly every German architect was acquainted with the contents of the essay without knowing the name of Robert Willis.

This was not remedied when contents from the essay were once more disseminated in a prominent publication: Again without any reference to its author, we find important parts of the essay, figures and text portions, in the manual on building construction (*Baukonstruktionslehre*) by Gustav Adolf Breymann, which was first published in 1849. Breymann, who was professor of architectural construction at the Polytechnic School of Stuttgart, initially presented it as a concise textbook in three volumes (construction in stone, in wood, in metal); soon it became the most influent manual of construction in Germany and remained such until the early 20th century, undergoing several re-editions and two major transformations by later authors. In spite of its concise and apparently uniform character, already the first edition authored by Breymann himself is in most parts a compilation of sources which are sometimes mentioned, more often not (Wendland 2008, 214–16).

The first volume, dedicated to stone construction and focusing mainly on masonry (while the subject of stereotomy is explicitly not included in the manual), contains a large section on vaults. Within this section, the chapters on the definition of the curves in Gothic vaults (Breymann 1849, 70–75) are based on Willis's essay, taking over large portions of the text in a literal translation (in particular Willis 1942a, 33 ff.). It is interesting to note that the wording is different from the previously published German translation, which suggests that it is an independent translation and that Breymann probably used the original publication of the essay —in particular, the terminology is coherent and corresponds well to the rest of Breymann's manual and also to the general use in the technical literature. Also the corresponding graphic material is obviously taken from Willis's essay: the adaptations made by Breymann integrate them to the rather uniform graphic style in his tables but in no way conceal their origin. Breymann's tables 30–33 contain illustrations from Willis's essay (Fig. 3–7); some of the drawings and two of the tables are maintained in all later editions (Breymann / Warth 1903, 288 fig. 833, 834; pl. 63, 64). Hence, contents of Willis's essay are widely disseminated in Germany also through this manual, while his name is not mentioned even once.

The chapter on the geometric design of the rib vault, or, as Breymann puts it, on "learning to know the procedures for finding the curvature of the ribs" (Brey-

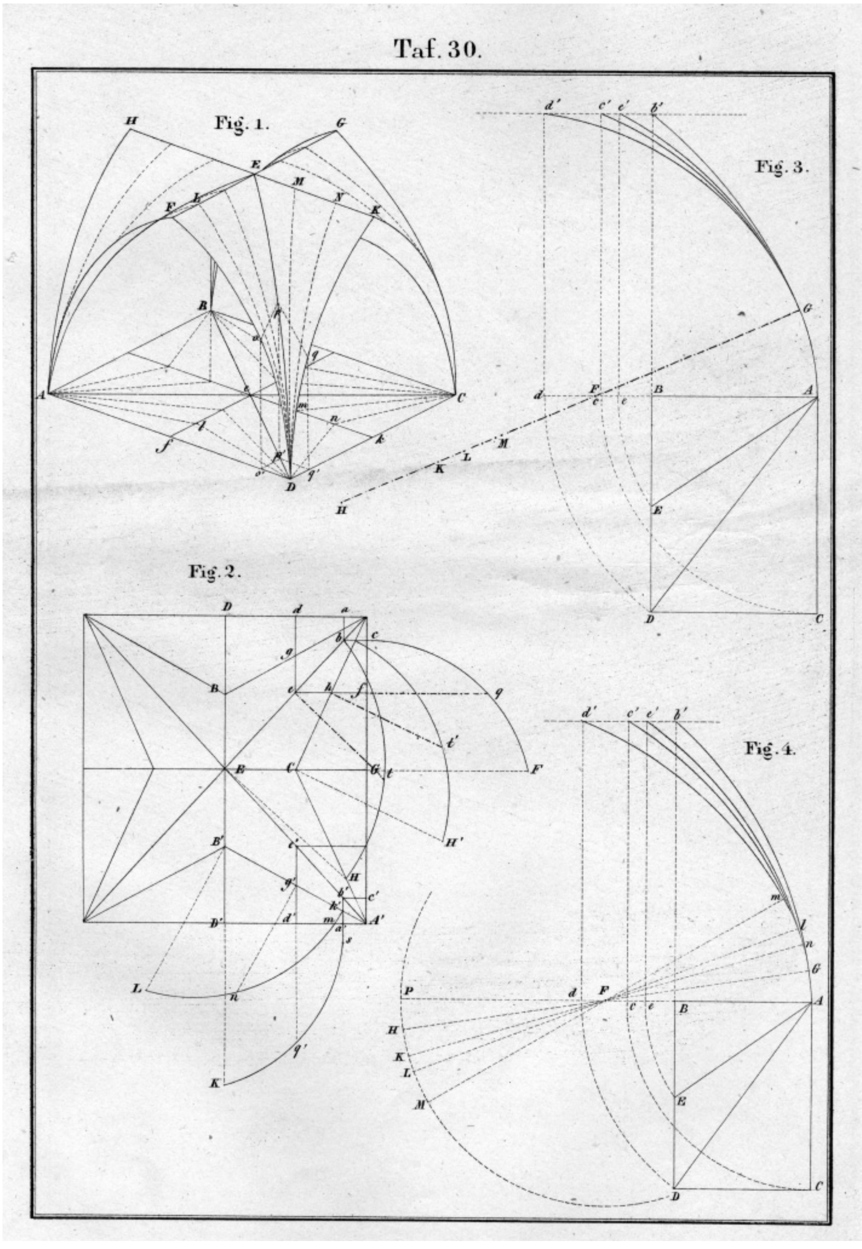


Figure 3.
Plate 30 in Breymann's *Baukonstruktionslehre* (1849) with adoption of graphics from Willis's essay on vault construction: Fig. 1 is a simplification of Willis's fig. 9 (1842a, 14), showing only the case of horizontal ridge ribs. Fig. 3 and 4 are based on Willis's fig. 11 and 12, fig. 2 apparently is based on his fig. 10 (Willis 1842a, 25, 26, resp. 19)

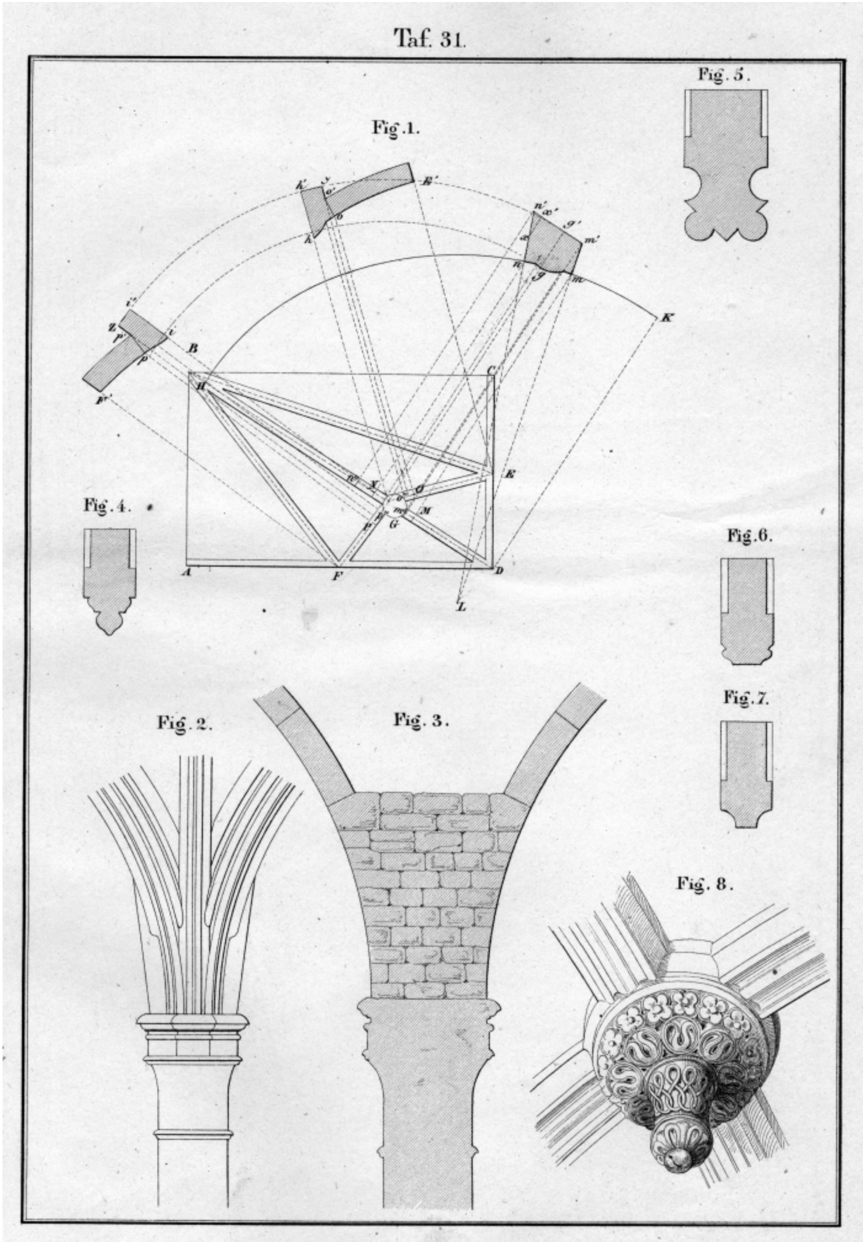


Figure 4.
Plate 31 in Breymann's *Baukonstruktionslehre* (1849): Fig. 1 origins from Willis's essay on vault construction (1842a, 32 Fig. 13)

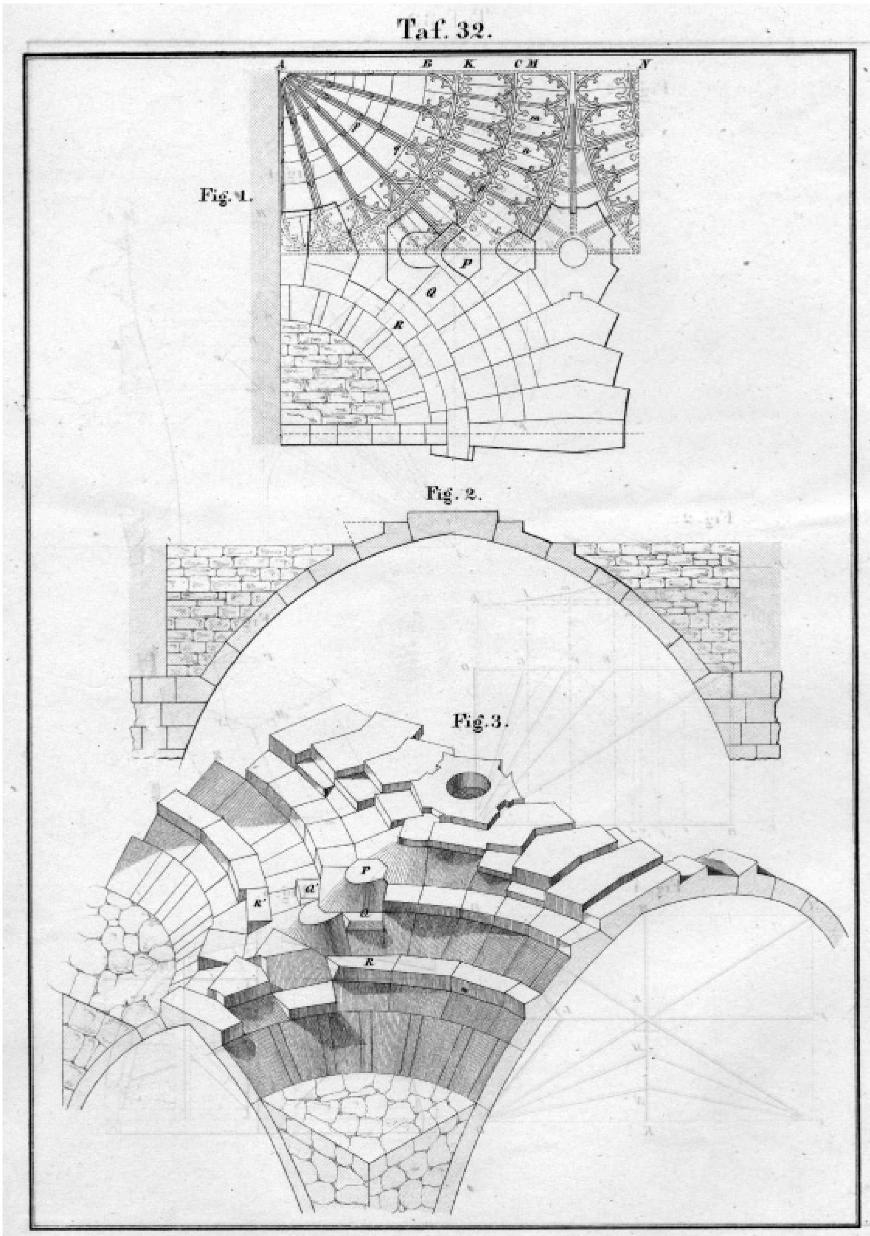


Figure 5.
Plate 32 in Breymann's *Baukonstruktionslehre* (1849) reproduces Willis's drawings of the fan vault in Peterborough (Willis 1842a, pl.1 fig. 25, pl. 2 fig. 26). This plate is contained in all re-edition of the treatise until the early 20th century

mann 1849, 70, our translation) is based on the explanation of the complex lierne vaults elaborated by Willis, according to which the ridge can either result from the definition of the liernes, or can be given a priori as plane arches or horizontal line. Although in Breymann's plate, the isometric drawing given by Willis (1842a, 15 fig. 9) is simplified, showing only the case of horizontal ridges (Figure 3), the text gives full account of Willis's considerations, including the construction of oval arches, i.e. ribs describing curves defined by two circle segments with tangential continuity. This is remarkable because, as already mentioned, these curves not common in Gothic vaults in the German speaking area; hence, we should consider it questionable to include such a special case in a general description of the design principles in a rather concise manual.[2]

But more important is the significant transformation the text undergoes due to the omission of all references to the existing historical buildings which are originally given in the text of Willis's essay: in Breymann's translation, none of the built examples on which the considerations are based is mentioned. In consequence, a central aspect in the historical interpretation of the analyzed vaults where Willis attempts to trace a development in the geometric design is reduced here to become a mere design option at the designer's deliberate choice. This is quite typical for the characteristic style of Breymann's manual, where the teaching of construction is predominantly based on the analysis of historical structures, but their description is always strictly limited to technical issues. Such stringency in general can be considered a quality of this book, which made it possible to concentrate the whole manual in only three volumes. But it is also problematic if a historical study of English medieval vaulting, although in its methodology very much apt to an application in architecture, becomes a technical description of how to build. The reader cannot comprehend that this description is based solely on analyses of historic buildings, and in no ways on the experience from practical application. Hence, the fact that the author and the provenience of the contents are not mentioned, constitutes a serious problem of reliability, which in the later editions of Breymann's manual rather increases and finally must have created serious difficulties to its readers. For us, it underlines the necessity of a profound critical analysis when dealing with historical technical literature as a source of information.

Also the next chapter "construction of the boss and its liernes" (Breymann 1849, 71–75) consists of long portions of text directly taken from Willis, again with some simplifications and omissions: Apart from eliminating all historical examples, Breymann shows no interest in the considerations on possible design criteria developed by Wills, about the "middle plan", and suppresses the passages where Willis describes the work on the full scale drawing which allows complex intersection stones to be designed without using descriptive geometry. Finally,

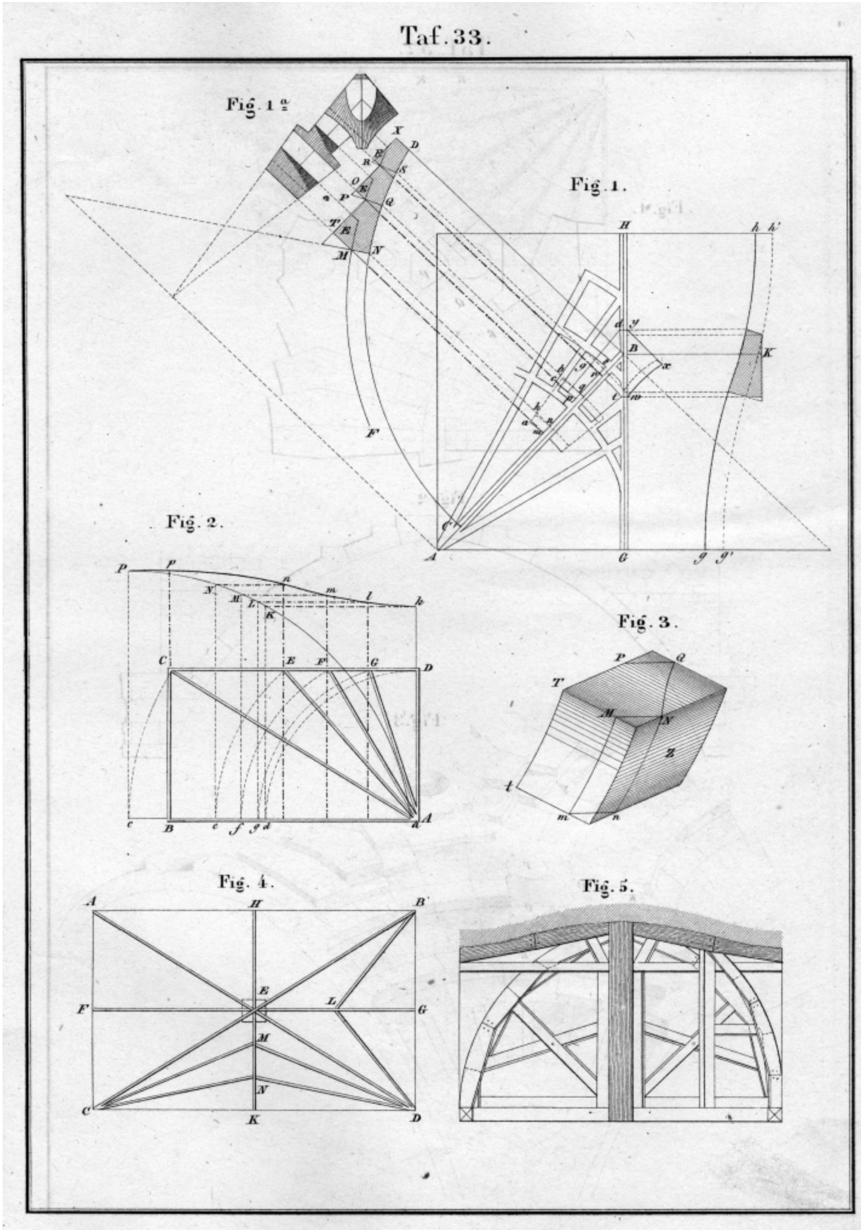


Figure 6.
Plate 33 in Breymann's *Baukonstruktionslehre* (1849), also dedicated to the construction of fan vaults, in the upper part reproduces drawings from Willis's essay. The illustrations of the centering in the lower part, however, are an original development based on the same geometry.

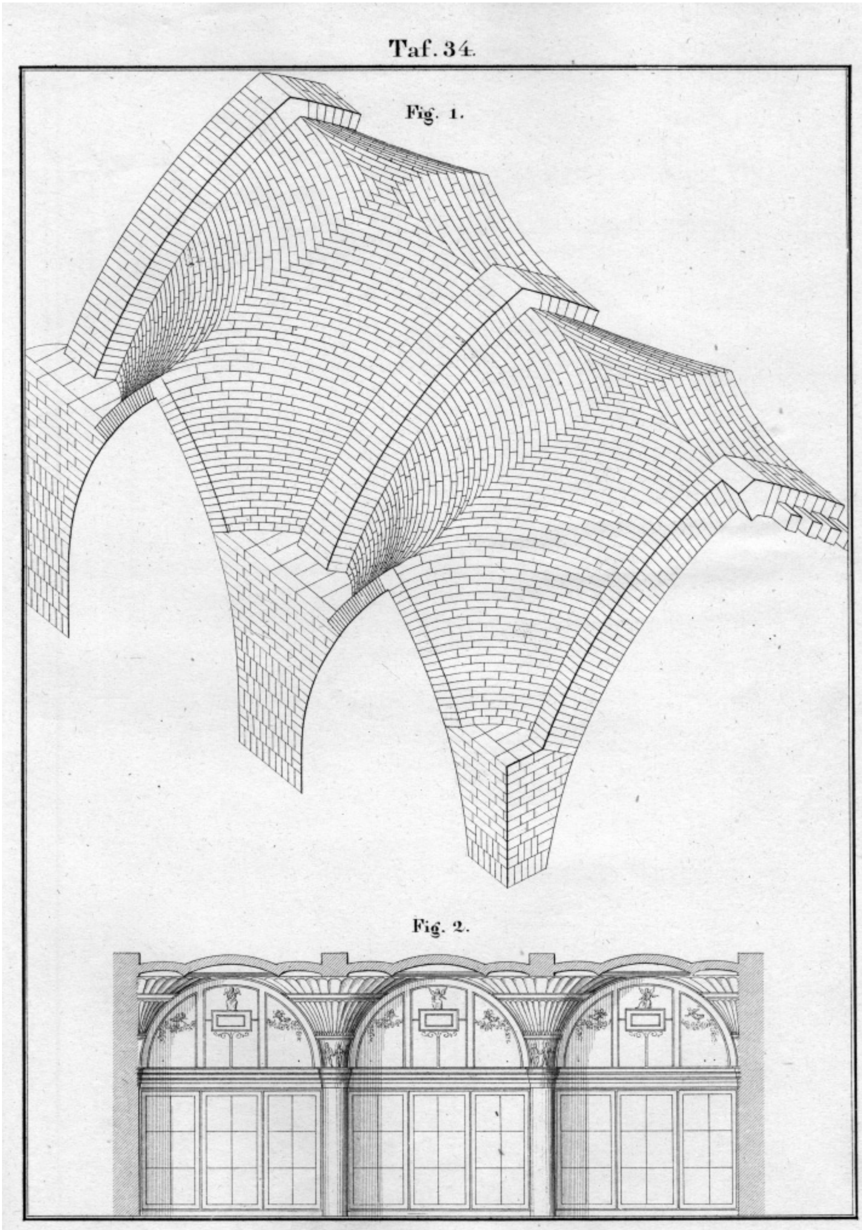


Figure 7.
Plate 34 in Breymann's *Baukonstruktionslehre* (1849) shows the adaptation of the fan vault to a brick masonry construction. The image in the lower part is taken from a contemporary description of the new vault in the stock exchange hall in Frankfurt (Germany).

the following description of fan vaults in the first part is again based on Willis. But then we find considerations on how vaults of the shape can be constructed in masonry, which are referred to a contemporary construction, namely the new building for the stock exchange in Frankfurt —in fact, masonry construction is of central interest throughout Breymann's manual.

In particular this last example shows the level of adaptation and reflection —the use of Willis's essay goes well beyond a mere rendition of text and images. The simplification of the isometric drawing showing the options for the definition of the arches and the ridge rib has already been mentioned (Breymann 1849, Pl. 30 fig. 1, our Figure 3). Significant is Breymann's addition to the graphics which originally explain the procedure of designing the single elements of fan vaults (Pl. 33, our Figure 6): Underneath the drawings directly taken from Willis (1842a, 47 fig. 21, 21a; 48 fig. 20), Breymann introduces the plan and elevation of the centering, where the curves of the radial arches and the ridge are traced in the same way Willis describes. This figure is somewhat problematic as it could be misunderstood for a rib vault. Breymann's intention, however, as clearly stated in the text (75), is to show how fan vaults can be also built in brick masonry. After demonstrating the solution for the geometric definition, the centering system and the complete masonry texture (Pl. 34, our Figure 7), in the following pages he presents a report on the new vault of the hall of Frankfurt stock exchange (76 and Pl. 34). All in all, this is an interesting attempt of realizing medieval architecture in modern construction, however light-years away from the "philological" quality of the considerations made by Robert Willis. Yet, Breymann's objective is that of a practical guide to building construction —quite different from an essay on the essence of the historical architectural design. It is crucial to clarify the sources and the character of their use in the manual, in order to be able to discuss the concept, quality and possible problematic of the science of construction in the teaching and technical literature of the 19th century.

For a third time, Willis's essay reaches the German reader through Viollet-le-Duc's *Dictionnaire*, which, although not translated, circulated in Germany and is often cited, for instance also in the later editions of Breymann's treatise (Wendland 2008, 219–223). Contents from the essay —Viollet-le-Duc uses the French translation of 1843— appear in the article "Voûte" in the 9th volume which was first published in 1868 (9:465–550). But obviously this hasn't been sufficient to acquaint the German readership not only the contents of the essay, but also the name of its author.

Robert Willis and the German Late Gothic vault architecture

As Robert Willis in his essay published in 1842 states with remarkable clarity, in order to understand Gothic vaulting it is necessary to comprehend the processes

of their construction and in particular of their design, such as the procedures of setting-out and of defining the geometric features of the single parts to be assembled to astonishing complex structures: These processes are determinant for the characteristics and the specific appearance of the built objects. For achieving this aim, today the conditions and possible strategies are quite the same as Robert Willis describes: Little information can be found in historical sources, and hardly any document of the design of a Gothic vault has survived.

The known sources —drawings from the pattern collections as well as the early treatises— are helpful to make assertions on the characteristics of architectural drawings and on the development of geometric procedures, in oder to determine a philological view on historical procedures and their development in the context of the knowledge society from the late Middle Ages to the Early Modern. But the main sources for the design of the buildings are the buildings themselves. As such, they can be accessed through the observation of the working traces and through analyses of the geometrical features by means of precise and detailed surveys —just as Robert Willis did. The key for their interpretation of the buildings as sources can be found by figuring out possible procedures which are plau-

Figure 8.
Intersection stone in the vault of the Hall of Arms, Albrechtsburg Meißen (Germany). The upper part penetrates in the shell; the top of the stone is a plane horizontal surface with marks and lines (Ventas / Wendland).

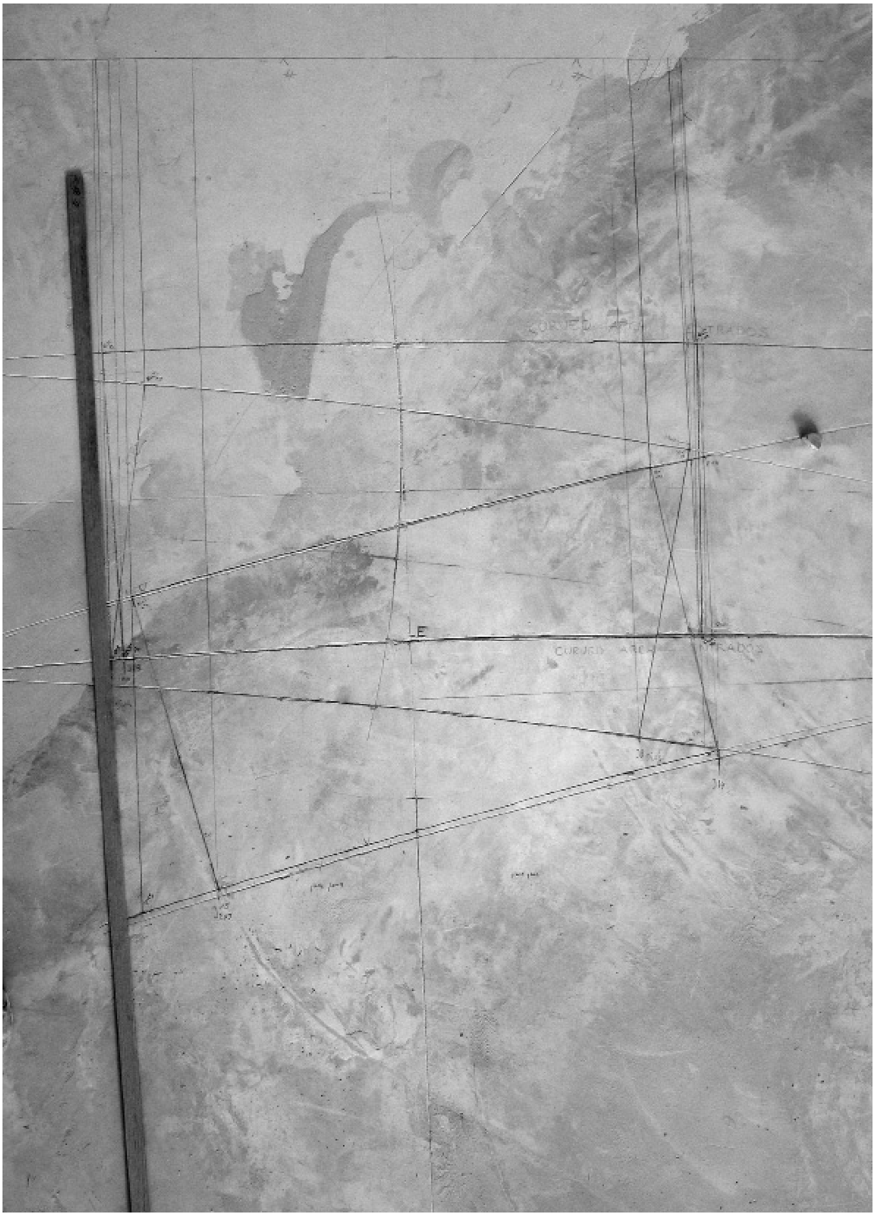


Figure 9.
Experimental reproduction of the intersection stone in Figure 8: extracting the heights from the full-scale drawing on the tracing floor (M.J. Ventas Sierra)

sible and which correlate with the sources, resuming them and checking them against the encountered working traces and the geometric features— clarifying the indices on whether or not these procedures could have been actually employed. The methodology which we find fully developed and transparently exposed in Willis's essay, today we call "reverse engineering".

Similar observations to those described in the essay can be also made on vaults in Germany. In particular, horizontal upper surfaces Willis describes, for instance, for the "boss stone" (1842a, 35, fig. 14), can be also found on intersection stones of complex late Gothic vaults in Germany, and they can be interpreted in the same lines as Willis does. This is the case, for example, in the vault of the Hall of Arms in the Albrechtsburg at Meissen (Figure 8), built by Jakob Heilmann in 1522 (Wendland 2012b and elsewhere). Here, the complicated intersection stones with the crossing of three ribs on different levels, in the upper part are formed as polygonal prisms, penetrating the masonry shell of the vault and having a plane horizontal surface on the top which carry marks and traced lines.[3]

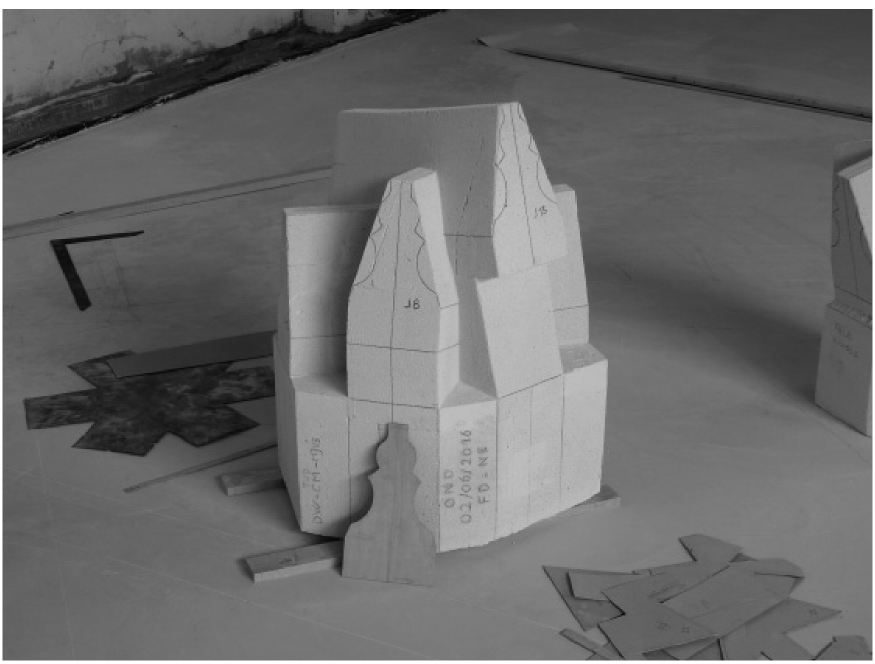


Figure 10.
Experimental reproduction of the intersection stone in Figure 8: intermediate stage with chamfered volumes of rib profiles (M.J. Ventas Sierra)

As we could learn from experiments carried out in full scale upon a detailed survey and geometric analysis, the geometric definition can be set out in a very straight-forward way on the full scale drawing (Figure 9), on which also the templates can be created. The essential information can then be easily extracted and transferred to the piece, using the horizontal surfaces as reference for all vertical heights (Figure 10). These experiments underline the central role of the full-scale drawing, in full accordance with Willis (1842a, 35–37), as well as the function of the horizontal upper surface which allows to simply turn the whole geometric definition upside-down. This interpretation can be validated through the geometric analyses of the surveyed building.

Hence, we can conclude that the essay by Robert Willis remains an important reference for discussion some archaeological evidence on late Gothic vaults in Germany —although it is not often cited, which may well be due to the circumstances discussed above. We esteem this to be one of the few texts from the 19th century which, beyond being a historical source for the time it was written, can still be taken in account of as a scientific position to be discussed and considered in the scientific investigation today.

Acknowledgements

The current research on Late Gothic vaults is carried out within the ERC Starting Grant "Design Principles in Late-Gothic Vault Construction —A New Approach Based on Surveys, Reverse Geometric Engineering and Reinterpretation of the Sources", which is receiving funding from the European Research Council under the European Union's Seventh Framework Programme, ERC grant agreement n° 284373. The mentioned experiments are currently carried out by the author with Christian Mai and María José Ventas Sierra in collaboration with Frédéric Degenève and Nicolas Eberhardt, Œuvre Notre-Dame de Strasbourg, within the ERC Proof of Concept Grant "Late Gothic vaults and their complex stone members: Recovering historical design procedures, implementing knowledge in restoration practice", which is receiving funding from the European Research Council under the European Union's Horizon 2020 programme, ERC grant Agreement n° 693779.

We want to thank Santiago Huerta for making accessible the publications by Robert Willis in a digital library, which opens the entire range of his writings for the scientific research and has been very helpful also for writing this paper.

Notes

1. For a profound and comprehensive exposition on the genesis of the Gothic revival, we refer to Germann (1974).

2. Apart from England, the use of oval arches has been described also in Spanish ribbed vaults (Palacios 2005). In Germany, this phenomenon is at the least not visible, but, as some observations from geometric analyses suggest, from a conceptual of view the possibility should be taken in account that over arches were at least part of the architects' repertoire (Wendland 2012b).
3. The archaeological documentation was carried out by E. Grotegut in 2007 (Dresden, Archive of the Landesamt für Denkmalpflege Sachsen). Bürger and Donath (2010) report the archaeological evidence and trace possible interpretations without being aware of Willis's writings and without noting the significance of the horizontal upper surfaces for the procedure of setting-out and carving of the work piece (Wendland 2013).

Bibliography

Breymann, Gustav Adolf. 1849. *Allgemeine Bau-Constructions-Lehre, mit besonderer Beziehung auf das Hochbauwesen*. *Teil I: Constructionen in Stein*. Stuttgart: Hoffmann.

Breymann, Gustav Adolf / Heinrich Lang. 1868. *Allgemeine Bau-Constructions-Lehre, mit besonderer Beziehung auf das Hochbauwesen*. *Teil I: Constructionen in Stein* (4th edition revised by H. Lang). Stuttgart: Weise.

Breymann, Gustav Adolf / Otto Warth. 1903. *Allgemeine Baukonstruktionslehre, mit besonderer Beziehung auf das Hochbauwesen. Band I: Die Konstruktionen in Stein* (7th enlarged and improved edition by Otto Warth). Leipzig: Gebhard.

Bürger, S. and G. Donath, 2010. Zeugnisse werkmeisterlicher Betätigung – Die Werksteine des Jakob Heilmann im Wappensaal der Albrechtsburg. In *Werkmeister der Spätgotik: Personen, Amt und Image*, edd. S. Bürger, B. Klein and K. Schröck, 232–243. Darmstadt, Wissenschaftliche Buchgesellschaft.

Germann, Georg. 1974. *Neugotik: Geschichte ihrer Architekturtheorie*. Stuttgart: DVA.

Lassaulx, Johann Claudius von. 1829. Beschreibung des Verfahrens bei Anfertigung leichter Gewölbe über Kirchen und ähnlichen Räumen. *Journal für die Baukunst*, 1.4: 317–330.

Lassaulx, Johann Claudius von. 1831. Description of a mode of erecting light vaults over churches and similar spaces (Communicated by Professor Whewell, of Cambridge). *Journal of the Royal Institution*, London, 1.1830/31, 225–240

Lassaulx, Johann Claudius von. [1835]. Architektonisch-historische Berichtigungen und Zusätze. In Klein, Johann August: *Rheinreise von Straßburg bis Rotterdam* (2nd extended and improved ed.), Koblenz: Bädecker.

Lassaulx, Johann Claudius von. 1846. Über Gewölbeformen: Vortrag des Bauinspectors von Lassaulx zu Coblenz in der Allgemeinen Architecten- und Ingenieur-Versammlung zu Gotha. *Zeitschrift für praktische Baukunst*, 6/1846, 423–427; also *Allgemeine Bauzeitung*, 376–380.

Lassaulx, Johann Claudius von. 1847. *Bausteine: Der Versammlung deutscher Architekten in Mainz vom 26. bis 28. August 1847 zum Willkommen am Rhein überreicht*. Koblenz: Hölscher.

Palacios Gonzalo, José C. 2005. The gothic oval ribbed vaults. In *Proc. International Seminar "Theory and practice of construction: knowledge, means, models"*, Ravenna 2005. 4:1653–1664.

Ungewitter, Georg Gottlob. 1859–1864. *Lehrbuch der gothischen Constructionen*. Leipzig: Weigel.

Viollet-le-Duc, Eugene. [1854–1868] 1875. *Dictionnaire raisonné de l'architecture française du XI^e au XVI^e siècle*. Paris: Morel.

Ware, Samuel. 1814. Observations on vaults. *Archaeologia* 17.1814: 40–84, Pl. VI–IX.

Wendland, David. 2008. *Lassaulx und der Gewölbebau mit selbsttragenden Mauerschichten. Neumittelalterliche Architektur um 1825–1848*. Petersberg: Imhof.

Wendland, David. 2012a. Johann Claudius von Lassaulx' Gewölbe "aus freier Hand" – Die Wiedererfindung der gotischen Architektur und die Entwicklung der technischen Literatur. In *Bautechnik des Historismus: Von den Theorien über gotischen Konstruktionen bis zu den Baustellen des 19. Jahrhunderts*, edited by Uta Hassler, Christoph Rauhut and Santiago Huerta, 92–117. München: Hirmer.

Wendland David. 2012b. Arches and Spirals: The Geometrical Concept of the Curvilinear Rib Vault in the Albrechtsburg at Meissen and Some Considerations on the Construction of Late-Gothic Vaults with Double-Curved Ribs. In *Nuts and Bolts of Construction History: Culture, Technology and Society,* 1:351–357, Paris: Picard.

Wendland, David. 2013. Zum Bau von figurierten Gewölben der Spätgotik: Planung, Formkontrolle, Konstruktion, Herstellungsprozess. In *Das Schlingrippengewölbe der Schlosskapelle Dresden*, 119–127. Altenburg: Kamprad.

Wendland, David; M. Aranda Alonso and M. J. Ventas Sierra. 2015. El corte de la piedra en bóvedas tardogóticas complejas a la luz de los primeros tratados modernos de estereotomía. In proceedings *Congreso Internacional Hispanoamericano de Historia de la Construcción*, Segovia, 3.1781–1791.

Wendland, David and M. J. Ventas Sierra. 2013. Designing a Masonry Shell in the Reconstructed Vault of the Palace Chapel at Dresden – An Attempt of Recovering the Forgotten Art of Late Gothic Vault Construction. *Informes de la Construcción*, 65.2013, No. extra 2, *Construcción Histórica en Piedra / Historic Stone Construction*, 49–63.

Whewell, William. 1842. *Architectural Notes on German Churches*, 3rd edition, to which are added "Architectural and historical remarks and additions" by J. C. v. Lassaulx. Cambridge: Deighton et al.

Willis, Robert. 1835. *Remarks on the Architecture of the Middle Ages, especially of Italy*. Cambridge: Deighton.

Willis, Robert. 1842a. On the construction of the vaults in the middle-ages. *Transactions of the Royal Institute of British Architects*, 1: 1–69.

[Willis, Robert]. 1842b. Ueber die Construction der Gewölbe im Mittelalter. *Zeitschrift für praktische Baukunst*, 1842: 192–222, Taf. 37–40.

Willis's sources on gothic vault construction

Santiago Huerta

Willis's article "On the construction of the vaults of the Middle Ages" marked a turning point in the study of Gothic vaults. It is still today the best exposition of the topic, a work to be studied with care by anyone wishing to know in depth how the cross-vaults of the Midle Ages were traced and built. Indeed, the word "construction" has the two meanings: we "construct" (trace) a curve, say, an oval with compass and rule, and we "construct" (build) an oval arch made of stone voussoirs with hammer and chisel on a centering.

The article has been cited many times; the splendid plates copied once and again. However, it seems that not many authors have dwelled in depth in its approach and content. It was cited, of course, in the fundamental work by Paul Frankl *The Gothic* (1960). But Pevsner (1970) in his monograph on Willis remarked that Frankl's book though an "invaluable study on the history of writings on Gothic architecture" was "weak on Willis". Pevsner didn't enter in the details of an "analysis [which] involved substantial technical and geometrical insights" ; however, he qualified it as a "fascinating paper" and reproduced, for the first time in many decades, one of the plates.

Middleton's long paper of 1962 on "The Abbé de Cordemoy and the Graeco-Gothic Ideal" completes Frankl's book, going into the details of the "Survival of Gothic" and studying "the rational interpretation of Gothic" in France, previous to Viollet-le-Duc. Middleton studies in this context the technical handbooks by De l'Orme, Frézier and others. Middleton does not even mention Robert Willis. However, Willis's work was known to Viollet-le-Duc, who drew extensively on Willis's paper for the article "Voûte" in his *Dictionnaire* (1854) (see also, Prof. Girón's essay in this book).

It was Alexandrina Buchanan in her dissertation of 1994, "Robert Willis and the Rise of Architectural History" who made the first thorough study of Willis's paper. In particular, Chapter 2 on "Vaults of the Middle Ages" discusses the paper in depth within the context of previous and contemporary English authors, and did extensive use of the original Willis papers in the Cambridge University Library (an impressive set of 32 vols, 10 box-files, 10 files and one bundle, which she catalogued for the CUL). Eventually, Buchanan's book of 2013, *Robert Willis and the Foundation of Architectural History*, is the definite work on Robert Willis.

The aim of the present paper is modest. It could be seen as a series of footnotes to Frankl's, Pevsner's or Buchanan's works, or to some of the more wide contributions contained in this volume. My objective is to describe the background against which the contribution of Willis should be judged. I will consider, then, the precedents concerning the tracing and construction of Medieval vaults as they appear in the sources cited by Willis himself in his paper.

Willis's aims

Willis work begins with an "Introduction" where he first made a review of the literature which contained information about gothic vaults. The list is not long and will be examined later. The conclusion was that there were no documents of the period covering the origin and development of high Gothic; this was true in 1842 and it is still true today. The only source of information were the buildings themselves. The main aim of his study is formulated clearly by Willis: "It becomes, therefore, a curious and interesting subject of inquiry to trace, from an examination of the structures themselves, what geometrical methods were really employed in setting out the work, and how the necessity for these methods gradually arose" (Willis 1842, 2).

Willis had not merely an antiquarian (historical) interest; at a time were the fascination for gothic led to build in this Style he wanted not merely to "copy" but to "design" following the fundamental principles: "we shall never succeed in obtaining the master key to their [gothic] principles, and instead of *designing* works in the style of any required age, we must content ourselves with merely *copying* them. [Willis's emphasis]

Willis discusses then the difficulties of the task: "For it will appear, as we proceed, that most of the facts required are of such a nature that they can only be derived from the existing buildings by the aid of scaffolding, minute measurement, and close observation, which it is not often in the power of mere travelling observers to obtain" (3), and expresses his hope the members of Institute of British Architects (the origin of the paper was a Lecture delivered in the Institute in July

1841) would contribute gathering facts.Unfortunately Willis's appeal was not followed neither for the members of the Institute nor for the next generations of gothic scholars.

Willis's sources

In his Introduction Willis cites a number of French and English treatises which contained information about medieval vaults. From France, he cites De l'Orme (1568 [1567]), Jousse (1642), Derand (1643), Desargues (1643), De la Rue (1728), Frézier (1738), and Jousse (1627) on carpentry. From Britain he only cites Halfpenny (1725) and Nicholson "whose various works on this subject are too well known to professional men to need enumeration". The French list is fairly complete; the English, succinct.

Along the paper he cites some other sources. The English translation by Whewell of Lassaulx (1829), "Mode of erecting light vaults over churches" published in 1831. Then, Ware (1822) *Tracts on vaults and bridges*. Two works by Nicholson: the *Builder's Director* (new edit. 1834) and the *Treatise on Masonry and Stonecutting* (1828). His own *Remarks* (1835) are cited twice. Then, several examples are cited from Pugin's *Specimens* and *Examples* which include the geometry of the wall ribs and cross ribs; also brief references to other historical works.

In all, the amount of references is small in comparison to the contemporary literature on gothic. As Willis states explicitly at the conclusion of his paper: "the methods which I have explained in this paper have been for the most part elicited from an examination of the existing vaults".

The method followed by Willis have been denominated "scientific": first, data are collected, and, then, a theory is formulated. However, what is often ignored is that a mere collection of data does not led to a "theory". As Darwin stated: "Without the making of theories, I am convinced there would be no observation" (letter to Charles Lyell, June 1860).

The basic assumptions of Willis are already contained in De l'Orme, Derand and Frézier. The plan of the ribs is the generator of the spatial vault. The ribs are arcs of circles or composed by arcs of circles. The precise curve of the ribs is determined by geometrical conditions: the profile of the liernes, the height of the bosses, the position of the centres, etc. The tas-de-charge is the necessary springing of the ribs and is produced by the intersection of the rib sections (templates). The rib skeleton is first constructed and, then, the webs fill the spaces between the ribs. These assumptions would have been considered obvious by contemporary French antiquarians, architects or engineers (tough they didn't mentioned them at the time) and were employed later by Viollet-le-Duc. The study of the

English treatises shows how much false premises could "blind" the observer. In fact, we could only "see" (understand) what we are able to see within a certain framework of knowledge. To think "against" a dominant framework is an extraordinary difficult exercise.

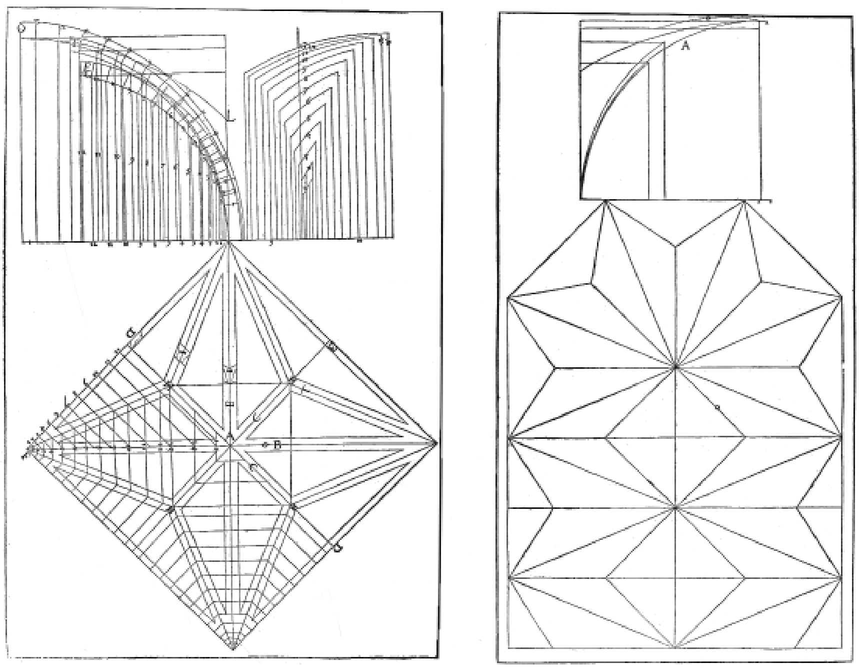
Willis did this, but he went much further. Measuring and analysing not a great number of vaults he was able to understand the great subtleties which may be hidden behind such evident and straight forward assumptions. Could it have been otherwise? Is gothic vaulting not an extremely refined art?

French authors: De l'Orme, Derand, Frézier

The main source of Willis is Philibert De l'Orme (1510?–1570). In his *Premier tome de l'architecture* (1567; reprint 1568), De l'Orme dedicated three chapters to the cross vaults which he called "voûtes modernes" or "croissée d'ogives". In the first chapter (Chapter VIII), he explained the construction of a typical cross vault. He begins with a kind of apology: these vaults are no longer built by architects who know the true architecture ("la vrye architecture"), however they have been found to be very good ("esté trouvées fort belles").

Then, De l'Orme describes a vault over an square plan with its "montée" (elevation of the ribs), Figure 1 (a). The exposition is systematic. First, he describes the plan of the vault, naming the different ribs ("branches") and locating them in the plan with capital letters: the diagonal arches *B* ("croisée d'ogives"), the transverse arches *E* ("arcs doubleaux"), the "tiercerons" *T*, the "liernes" *C* and wall ribs *D* ("formerets"). The central boss is marked *A* and the secondary bosses *H*. The sections templates of the ribs ("les petites moules des ogives") are *I*. (Willis incorporated the terms "lierne" and "tierceron" to the English nomenclature of gothic vaults.) Then, De l'Orme describes briefly an essential part of the vaults: the "tas-de-charge" (term which also has found a place in English language), formed by the first stones which receive the springings of the ribs, "ce sont les premieres pierres que on voit sur les angles, et mostrent le commencement et la naissance des branches". Willis in his *Nomenclature* defined it as "The solid block of masonry which projects from the wall, and upon which the ribs rest" (Willis, 1844, 44).

On the left top of the drawing the profiles of the ribs are drawn: *O* the diagonal arches, *T* the tiercerons, *E* the wall and transverse arches, and *S* (on the right) the liernes. De l'Orme do not explain in detail how to trace these arcs of circumference. He only says that with a compass, and beginning, with the diagonals, it is possible to know them from the projection in the plan. De l'Orme explains that *AF*, the demi-diagonal of the plan, is the radius of the diagonal arch *O* in the elevation. But gives no more indications as how to obtain the rest of the arcs, just saying that the



(a) (b)

Figure 1
(a) Plan and rib elevation ("montée") of a cross vault (De l'Orme 1567, 108v); (b) Plan and rib elevation of chruch vault ((De l'Orme 1567, 109v)

procedure will be the same, because, he says, these things could only be shown in the practice of building. See Figure 2, for an explanation of the procedure.

The right part of the drawing show the form of the webs above the ribs, which after De l'Orme is the most difficult part if they are made of ashlar masonry, with the stones perfectly cut to fit between them. He insists in the next chapter on this difficulty, remarking that in most cases they are built of soft stone or brick, ". . . la plus part des pendentifs de voutes d'eglises, ne se font de pierre de taille . . . pour la difficulté qui sy presente. Et de la vient que souvent on les faict de brique, ou de quelque pierre tendre de moilon" (109r). (But the medieval masons never considered this possibility: the essence of gothic construction is to avoid unnecessary work. This mere intention puts De l'Orme outside of the gothic tradition.)

In the next chapter (Chap. IX), De l'Orme gives the example of a gothic vault for a church, showing the church's head as a half octagon (Fig. 1(b)). The drawing seems to be a copy of an actual trace. The skeleton of ribs is represented in plan

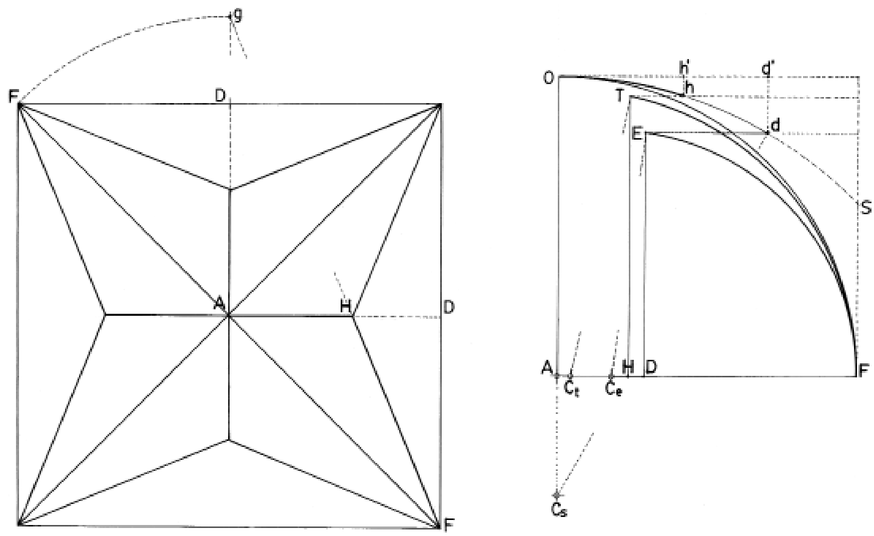


Figure 2
Exaplanation of Figure 1(a). Plan and elevation drawn separately. Procedure: 1) Draw the *diagonal rib*: arc *FO* with centre in *A*; 2) draw the *wall/transverse rib*: locate point *D* (*DF* determined in the plan); either locate centre C_e (or fix the height *DE*) and trace the arc *FE*; 3) draw the *lierne*: the lierne must pass through the keystone of the diagonal arch, *O*, and the keystone of the wall/trasnverse arch *E*; then *Od'* in the elevation must be equal to *DF* in the plan; tracing the horizontal through *E* we obtain *d.* Trace the arc which passes through points *O* and *d* with centre in the vertical *OA* (centre C_s).

and elevation by lines. De l'Orme considers the vault of considerable strength due to the cross linking of the ribs, "la dicte voute sera forte pour les branches qui y sont entreliées, et s'entretiennent toutes ensemble, comme vous le voiez" (109). He remarks that it is not necessary to draw the thickness of the ribs, as the masons would know how to assign them ("les ouvriers les sçauront bien faire").

Then, De l'Orme describes how to cut the joints among the stones. He probably refers both to the ribs and the masonry of the webs. The joints must concur to the centre; the intrados should be dressed smoothly, without visible irregularities, following always the circle lines of the elevation: ". . . les couches des licts de la maçonnerie soient toujours faictes par lignes droictes, et qui proviennent du centre don't est tirée la montée, et que les branches soient conduictes à droite ligne, et par le dessous avec leurs cyntres, sans que leur circonference face aucun jarret . . . Mais il ne fault oublier que le tout *doit estre conduict suyvant la circonference du compas*". [my emphasis]

The thickness of the joints ("conmissures") should be as thin as possible so that it would not be necessary to use wooden wedges between the stones. Also, the joints being thin, it is unnecessary to use much mortar, but only to grout with fluid mortar ("laictance"): "Sur tout il fault user des plus petites conmissures qu'on pourra, a fin qu'il n'y faille de grandes escailles, qui sont morçeaux de bois qu'on met entre les ioincts. Il ne fault aussi y employer grand mortier, ains seulement les abrever de laictance, qui est la graisse de la chaux, resemblant à du lait, don't elle prend le nom."

Examining De l'Orme's drawings it is not difficult to find the essential assumptions. First, as we have seen, all the ribs *OF* (diagonal), *TF* (tiercerons) and *EF* (wall and transverse ribs) have a vertical tangent, so that the centre must be in the impost line. Second, and this is not so evident, the arc of the liernes *S* pass through the central boss *O* and the keystone *E* of the wall and transverse ribs (see Figure 1). Thirdly, once defined the position of *E*, it is possible to find the centre of arc *L* and, afterwards, to project the secondary boss *H* on it, obtaining the height *T* of the arc of the tierceron. Steps two and three could be reversed: instead of defining the height of the wall and transverse arches, we could decide first the profile of the liernes, selecting arbitrarily the center on the vertical passing through *O* in the elevation, or, as it occurs many times, deciding that the liernes are horizontal. Or it may be that the liernes *AH* are curve and the points *H* and *E* have the same height, which is also not uncommon. The practice have been resumed in Figure 2, where the elevation of the ribs have been drawn separately.

The "method of projection"

Willis cites another book by De l'Orme, his *Nouvelles Inventions* published in 1561 (Willis used the 1578 edition). There it appears published for the first time a method to trace surbased arches from a semicircular arch. De L'Orme called this arches "cherches rallongées", which may be translated freely as "stretched" or "lenghtened" arches or centerings, and which Willis named "the method of projection". (The method had probably great diffusion in late-gothic in all Europe as there are 16th Century examples in Spain, France, Germany and Italy. It was first published by Albrecht Dürer in his *Unterweisung der Messung* (1525).) Willis cites also the stone-cutting treatise by Jousse (1642). Jousse employed the expression "courbe rallongée" also, and as Willis remarks, "The fact of this problem having a familiar name shows that it was of common use amongst workmen." The same procedure appears, as we shall see, also in the the carpentry treatise of the same author published earlier (Jousse 1627).

From a geometric point of view it is indeed a method of projection. However, it is doubtful that the medieval stone masons used it with this awareness: proba-

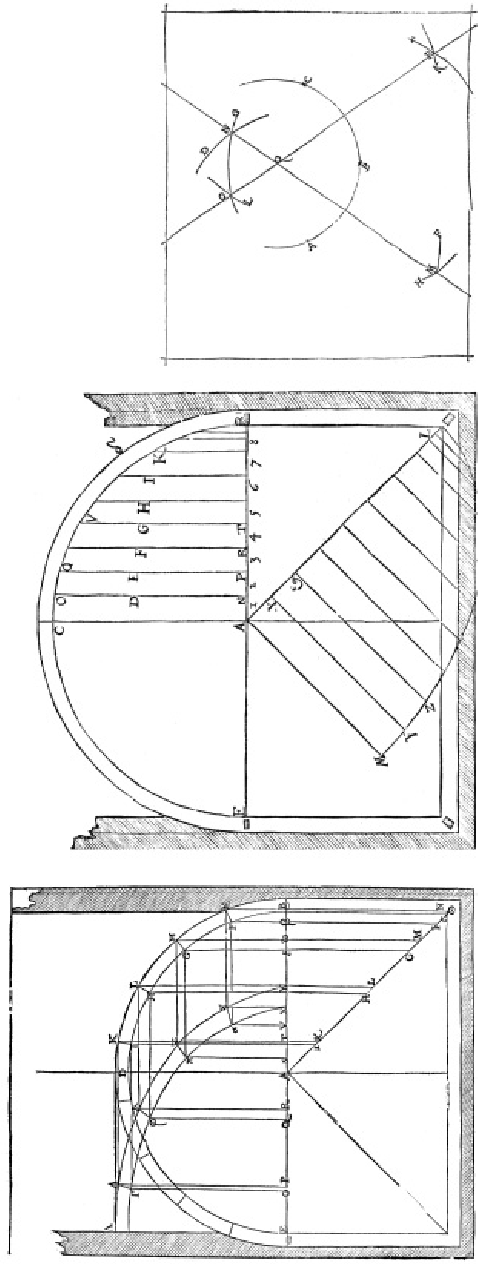


Figure 3
Lengthened arch: (a) and (b) Two methods to draw a “cherche rallongée” for the ridge of a square cloister vault; (c) Method to find “les trois points perdus”. (De L’Orme 1561)

bly it was a "receipt", a procedure composed of several steps which leads to the desired result. As we shall see, English architects and carpenters of the 18th Century employed it widely.

De L'Orme used two different representations of the method, applied in both cases, to a vault in "cul-de-four" (a cloister vault), Figure 3 (a) and (b). In both methods the generating arch, the section through the middle of the cloister vault, is divided into a number of parts. Vertical lines are traced which cut the horizontal line *AB* and the diagonal *AO*, giving the vertical and horizontal coordinates of the points of the stretched arch. In the first method, Fig. 3 (a), the arch is drawn on the springing line; in the second, Fig. 3 (b), on the diagonal.

The curve obtained is an ellipse, which has a varying radius of curvature. For a stone mason this would have been a problem, because he needs geometric templates for each voussoir: in the ellipse each voussoir of a demi-arch will need a different template. But, ¿what would be the radius for each one?

De L'Orme teaches the reader how to do this in a chapter entitled "Maniere de trouver les trois poinctz perdus pour s'en aider à faire les cherches r'allongées" (Way to find the 'three lost points' to help to trace the stretched arches), Figure 3 (c). The construction is evident for the modern reader: tracing arches with the compass from the three "lost" points *A*, *B*, *C*, we trace perpendicular lines to segments *AB* and *BC*, and the point of intersection *Q* is the centre of the circumference passing through the three points (which are no longer "lost").

De L'Orme instructs us to take each three points in turn, to obtain an smooth curve ("sans qu'il y ayt iarret"). However, as every circumference would have different radius, with a different centre, it is not clear at all how would it be possible to avoid discontinuities. I have found the key to the procedure in another drawing from the carpentry treatise by Jousse (1627), Figure 4 (a). Once obtained the "lost" points of the new curve, *1*, *2*, . . ., *9*, *D* in Figure 4 (b) , we trace perpendicular lines to each of the segments between the points (*9*", *8*", etc.). The intersection of *9*" with *8*" gives *D*'; from this centre we trace the arc *D8"* to the first point of tangency. Then, with centre in *9*", passing through *9*, to the next point of tangency, and so on.

In this way we obtain a polycentric "smooth" curve, a precedent of the curves employed in the 18th and 19th for surbased arches in the bridges. The procedure must have been tedious for the masons or carpenters, but de L'Orme (and Jousse) wanted to obtain an exact template for every voussoir (piece of wood).

Derand, Frézier

François Derand (1591–1644) was the next French author to dedicate some attention to gothic vaults. In his *L'architecture des voûtes* (1643) he gives a de-

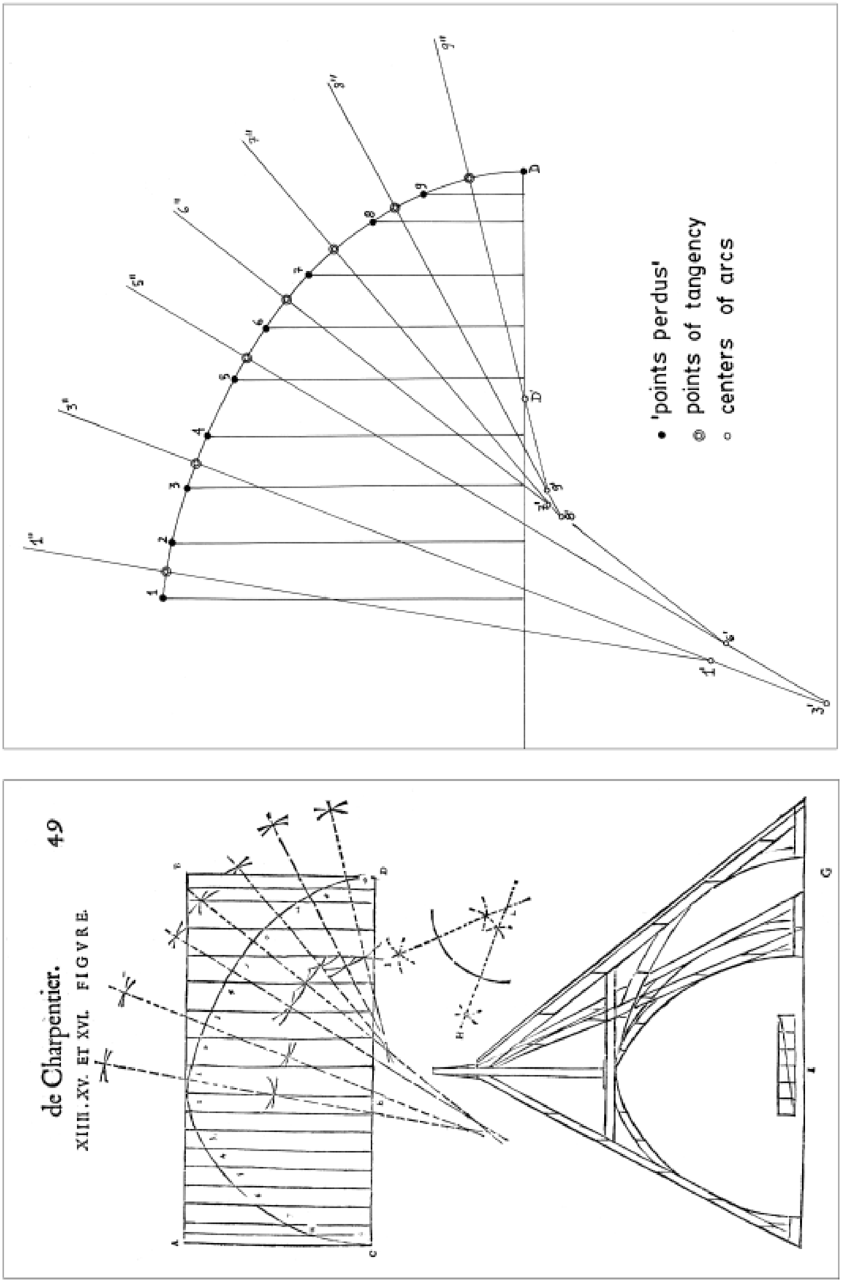


Figure 4
(a) Plate from Jousse (1627, 49), showing the method to draw the "courbes rallongées" for the design of trusses; (b) explanation of previous figure

scription based in De l'Orme. The plan is the same and so is the method to obtain the radii of the ribs, which are also drawn separately, Figure 5 (a). There are some differences which show the different date of publication: for example, Derand considers the possibility of forming a wall or transverse rib with a semicircular stilted profile (and this was criticised sharply by Frézier). But, in essence, the procedure is the same.

However, his comments about the construction of the tas-de-charge are most pertinent (Derand do not use the term "tas-de-charge" for gothic vaults). To him, this is also the most difficult part, as there concur the different ribs in an small space where they interpenetrate. Besides, in elevation, each rib moves with a different radius and different direction and, as a consequence, some are seen entirely and other only in part, and only the practice would permit to understand the problem: ". . . comme on vient à les élever, les uns prennent leur contour d'un costé, les autres de l'autre: quelques-uns paroissent entiers dés leur origine, quelques autres ne paroissent qu'en partie, d'autres ne se monstrent qu'à une certaine auteur, comme la pratique le fera mieux voir, que tous les discours que nous en pourrions faire icy." (Derand 1643, 394)

However, Derand tried afterwards to explain the procedure. First, the templates of the ribs should be placed in their position (on a horizontal plane), tracing then their contours and marking some with dotted lines, others continuous lines, or with ink or pencil of different colours, as is necessary to distinguish clearly in the plan which lines are free and protrude, and which lines remain embedded within the others: ". . . pour en venir plus facilement au bout, il faut que vous placiez sur le pIan, au lieu où les dits nerfs se rencontrent, la forme et façon d'un chacun d'iceux, les y traçant fuivant la diverfe situation qu'ils y doivent avoir, marquant les, uns avec les lignes ponctuées, les autres avec lignes pleines, même vous servant d'ancre ou de crayon de diverfes couleurs, lorfque la multitude des dits nerfs l'exigera pour en mieux éviter la confusion: car ce faisant vous remarquerez plus aisément sur vostre plan, quelles parties d'iceux se trouveront libres et dégagées, et quelles envelopées les unes dans les autres." (395)

Next, considering the curvature of each rib it would be easy to ascertain, at which height some ribs begin to protrude and which are completely free: "Et tirant sur chacune d'icelles les cintres qu'elles doivent avoir, il vous fera facile de reconnoistre à quelle hauteur elles commenceront à paroistre, et à quelles elles se trouveront tout à fait dégagées".

Derand finish his exposition making some considerations about the sections of the ribs, and about the convenience of making templates of each one of them (ogives, arc doubleaux, tiercerons, formerets et liernes). After Derand, cross ribs and tiercerons should have the same thickness and form ("moulure") so that the meeting of both ribs at the boss would be more satisfactory ("plus agreable").

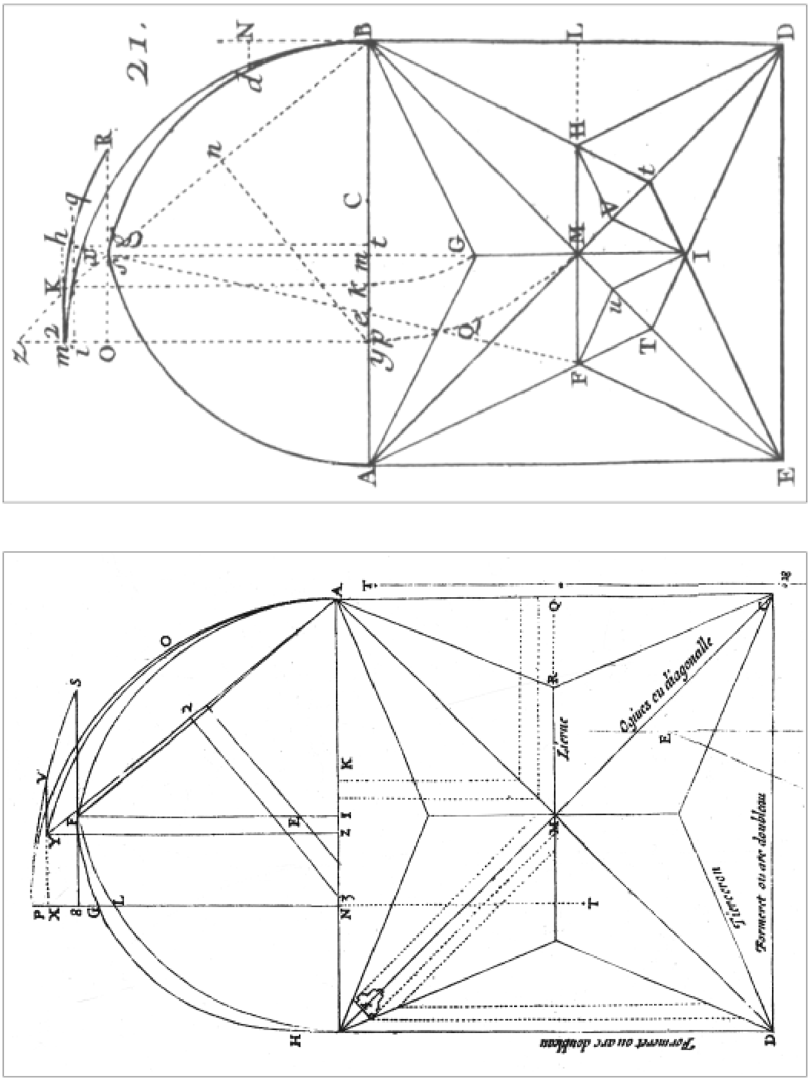


Figure 5
Tracing of a gothic vault: (a) Derand (1643, 377); (b) Frézier (1739, Pl. 71) (cf. Fig. 6)

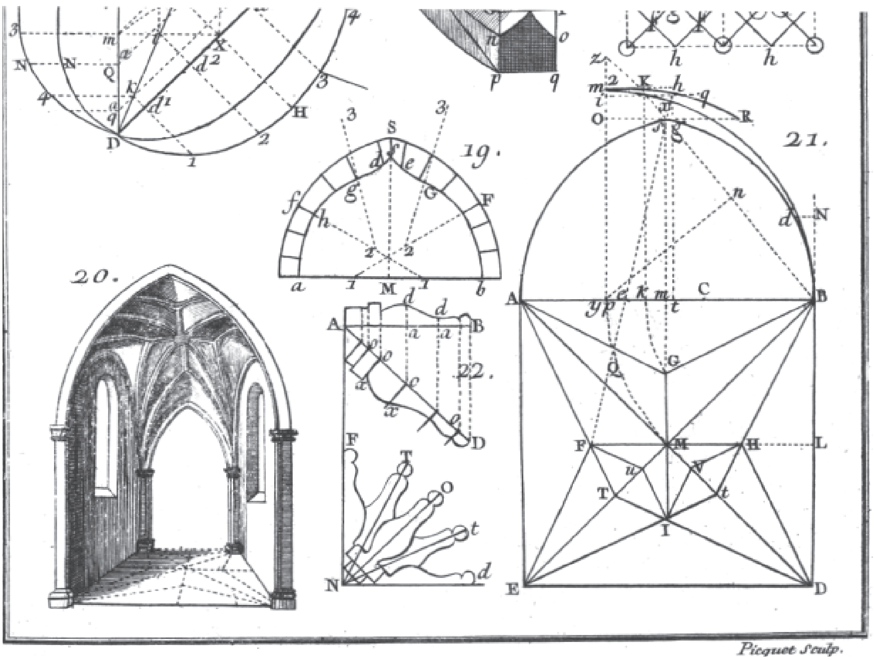


Figure 6
Frézier on gothic vaults. Note the sketch to explain the construction of the tas-de-charge, *22.* in the plate (1739 III: Pl. 76)

Amédée François Frézier (1682–1773) published in 1737–39 his three volumes of his *La théorie et la pratique de la coupe de pierres*, the most important treatise on stereotomy ever written. He dedicates also some pages to gothic vaults. His comments about their advantages show a deep understanding of masonry construction and also a dislike to gothic forms, particularly to the pointed arches.

Frézier dedicates eight pages to the gothic vaults ("voutes d'arêtes gothiques") in the third volume of his treatise (Frézier 1739, III: 24–31). Frézier justifies his discussion on grounds of the necessity of reconstructing some parts of them in the maintenance of existing buildings: ". . . mais comme dans les réparations des anciens Cloîtres, Eglises, ou autres Edifices, il se présente des occasions d'en rétablir quelques parties, il est nécessaire d'en connoître le Trait" (25). Frézier cites Derand, but not De l'Orme. The exposition is more systematic but the content is essentially the same. The same vault plan and the same way to trace the different ribs which appear drawn separately on the top, Figure 5 (b).

Frézier agrees with Derand that the most difficult parts in gothic building are the intersection and the springing (tas-de-chartge) of he ribs. For the intersections he considers convenient that all the ribs have the same section ("moulures égales"), again following Derand. As regards the springing or tas-de-charge (which he calls "cu-de-lamp"), he says it is necessary to make a projection as *N* in Figure 6 (*22.*), marking the directions of the ribs: *NF* the wall rib or "formeret", *NT* the tierceron, *NO* the cross rib or "augive", *Nt* the other tierceron, and *Nd* a transverse rib or "arc doubleaux". He notes that the main ribs (*NF, NO, Nd*) cover the others. To know at which height the ribs become free it is necessary to look at the projection or salience of the ribs at different heights; for example considering *d* at height *BN* in Fig. 5 (b). Then, drawing again the sections of the ribs in plan for this height it is possible to know if all the ribs are free or are still covered by the main ribs. The explanation is incomplete and it is evident that Frézier is resuming a common practice among the workers, which was unearthed more than a century later by Willis.

English authors: Halfpenny, Ware, Nicholson

In the making of a theory it is important to be able to discard common beliefs. In England around 1800 circulated several methods to construct pointed arches and the "groins" (cross arches) of gothic vaults which were simply fanciful; so we will consider them nowadays. But he fact is that these methods have been published continuously for a century and formed part of the cultural background. First thing to conduct a research on gothic tracing methods was to get rid of them.

Halfpenny, Nicholson

It appears that these methods were introduced by William Halfpenny (–1755), carpenter by formation, who published numerous manuals (20 are cited in the *DNB*) on building, geometry, arithmetic, perspective, . . . and gothic and chinese architecture. Perhaps the more influential was his *Art of sound building* published in 1725.

Halfpenny's offer no more than a collection of rules with two novelties, Figure 7: 1) he introduced a method to draw an arch by tangents, which may easily adapted to any form; 2) he made extensive use of the method of projection. But Halfpenny is an eclectic; he gives also the construction of pointed arches by arcs of circumference. In fact, The book is a collection of step-by-step rules, without any geometric explanation or inquiry on the nature of the curves involved. (This construction first appeared in France at the end of the 17th Century. It appears

that it was first published by La Hire (1702) who demonstrated that the curve is a parabola.)

Both methods were diffused in the English building manuals of the 18th Century (by Batty Langley, William Pain, Francis Price and others) and they appear still in the first half of the 19th Century. Willis was very critical to Halfpenny "who, living at period when Gothic architecture had sunk into complete neglect, may very well be excused for having misapplied as he has done the projection system to the finding the 'Mitre Arch of a Regular Groin when the Intersecting Arches are Gothick ones'" (Willis 1842, 22), Figure 7 (*Fig. 22*).

Willis cites also Peter Nicholson (1765–1844) author of numerous handbooks on building. Willis is particularly acid with Nicholson "who has also taken much trouble to construct a Gothic vault with *cuniconoidal surfaces* and upon other fanciciful hypotheses, which, as they produce curves for the ribs totally different from the genuine ones, can answer no purpose but that of destroying the mediaeval character of the work", Figure 8.

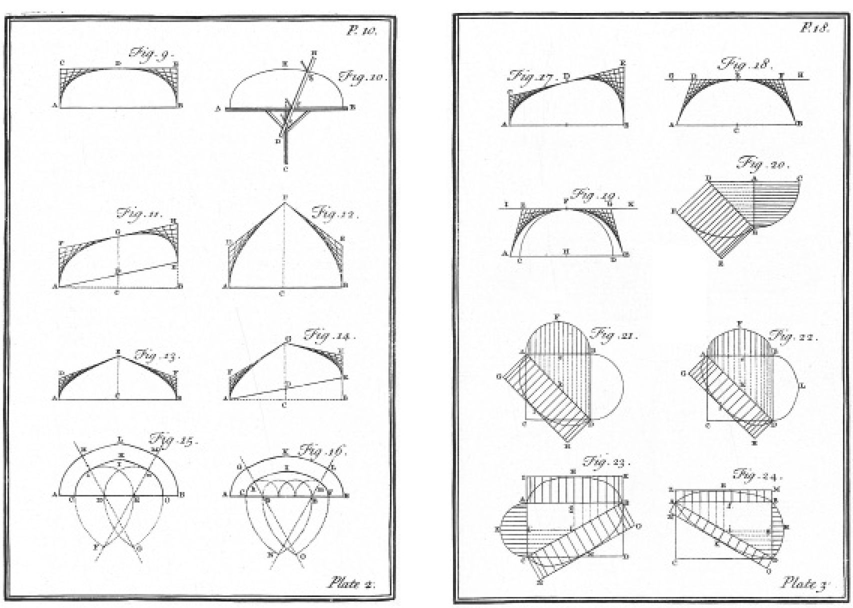
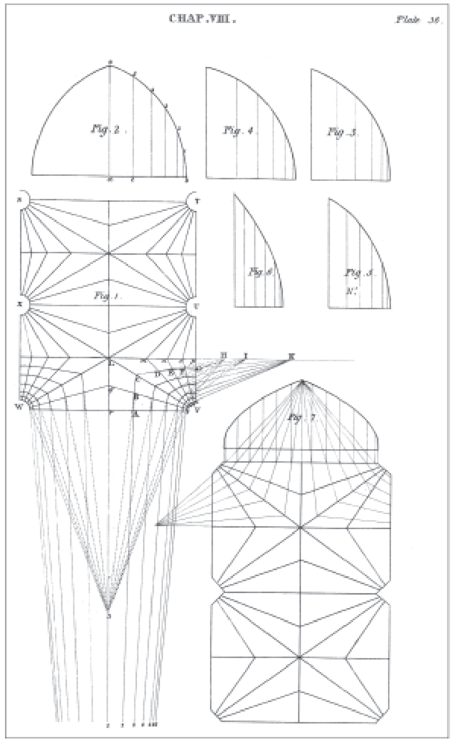


Figure 7
Plates from the *Art of sound building* (Halpenny 1725) showing the construction of arches and groins



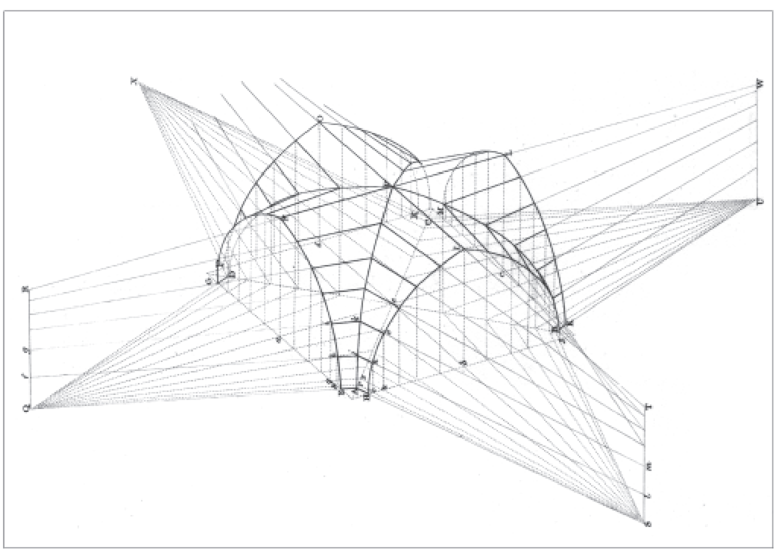


Figure 8
Gothic vault made of “cuniconoidal surfaces” after Nicholson (1828)

Pugin

Augustus Charles Pugin (1762–1832) made very accurate drawings of gothic vaults and buildings, which he published mainly in his *Specimens* (1821–23) and his *Examples* (1828–1831), with several reprints and editions. He collaborated with Britton and Le Keux in the *The Architectural Antiquities of Normandy* (1828) where he made detailed drawings of the churches in Caen. What was of interest to Willis were the detailed drawings of the vaults, in particular when Pugin draw the geometry of the ribs.

From the *Specimens* Willis quote two vaults. The first is a diagram of the vault on the east side of the cloisters at Westminster, Figure 9. The drawing shows all the ribs springing from the corner on the same line, the diagonal of the plan, instead of in a separate diagram as Philibert (Fig. 1) or Derand and Frézier (Fig. 5). But, making abstraction of this, the diagrams are evidently constructed on the same principles. Willis remarks that all the ribs have the same radius, "*the diagonal rib has the same radius as the transverse ribs*" (Willis 1842, 17) —which is nearly true, and omits saying that also the tiercerons have very nearly the same radius also. Willis was interested in the principle "of employing a common radius for the diagonal and transverse ribs [which] agrees with many other examples".

In fact, Pugin was reinterpreting a drawing from Rondelet's *L'art de bâtir* (first edition,1802–1817; probably the most popular building manual of the 19th Century.) Rondelet dedicates several pages in the second volume to the study of gothic vaults. Figure 10 shows the plan of a "voûte gothique à triple àretes" which correspond to the church of Saint Gervaise in Paris. The plan of the vault is square but is of the same type of the previous Westminster vault (upon a slightly rectangular plan). It is obvious that Rondelet was the source of Pugin's drawing though it is also evident that Pugin has studied and redrawn the plate. What effect produced this in Pugin? It is impossible to know, but it is a fact that only after this first volume of the *Specimens* Pugin began in a systematic manner to indicate the centres and curvatures of arches and vaults in his drawings, and his section of the church of St. Ouen in Caen, he measured and drew the cross arch of the lateral aisles (Britton 1828, Pl. 4).

The second drawing from Pugin cited by Willis, published in the second volume of the *Specimens* (1823), is from the vault of the Lady Chapel in St. Saviours, Southwark, Figure 11. It is a cross vault with horizontal ridges and what is remarkable is the constructive detail of the drawing. Indeed it was made by George Gwilt in 1822 during his work of restoration of the vaults (Gwilt 1857).

The profile of both the cross and transverse ribs are given. For the transverse rib he measured the height of the arc, considering it an arc of circumference, and then geometrically found the centre which is under the springing

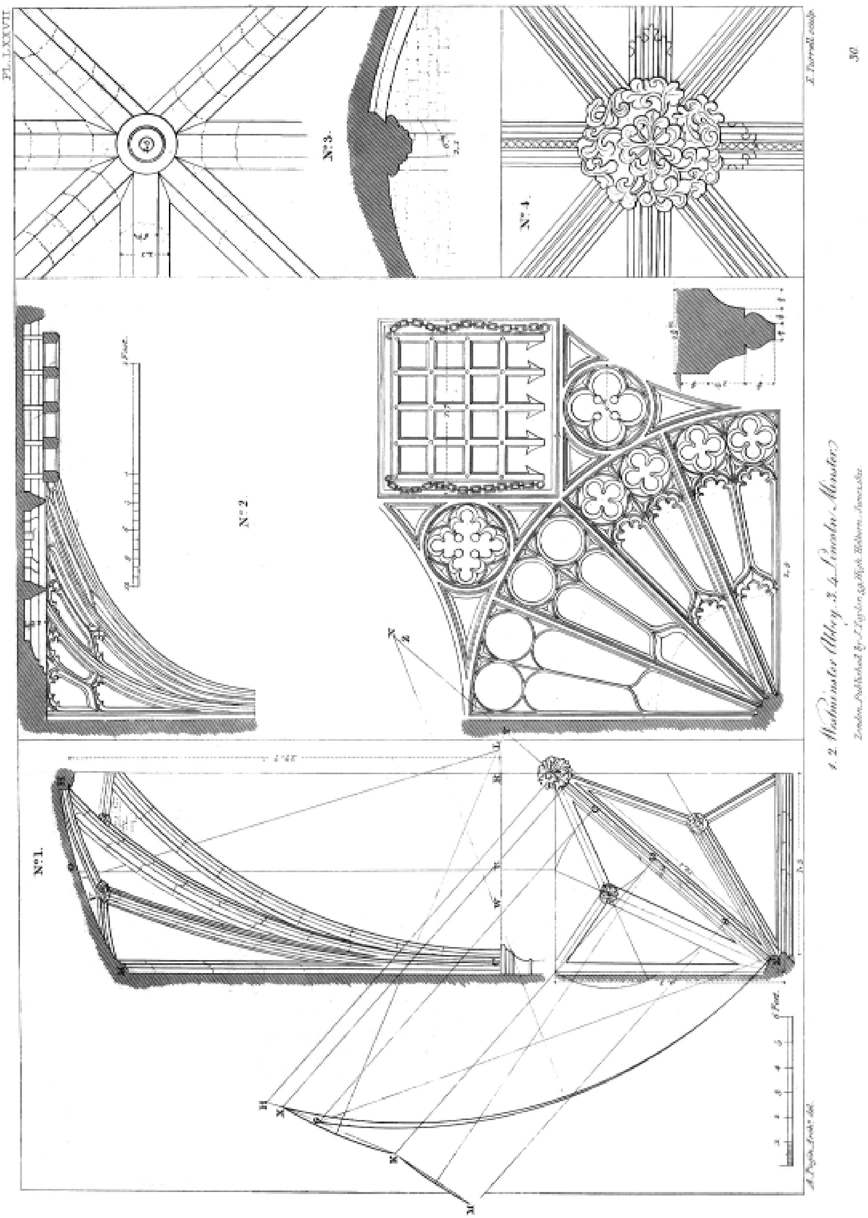


Figure 9
Vault on the east side of the cloisters, Westminster (Pugin 1821, *Specimens* vol. 1, pl. 77)

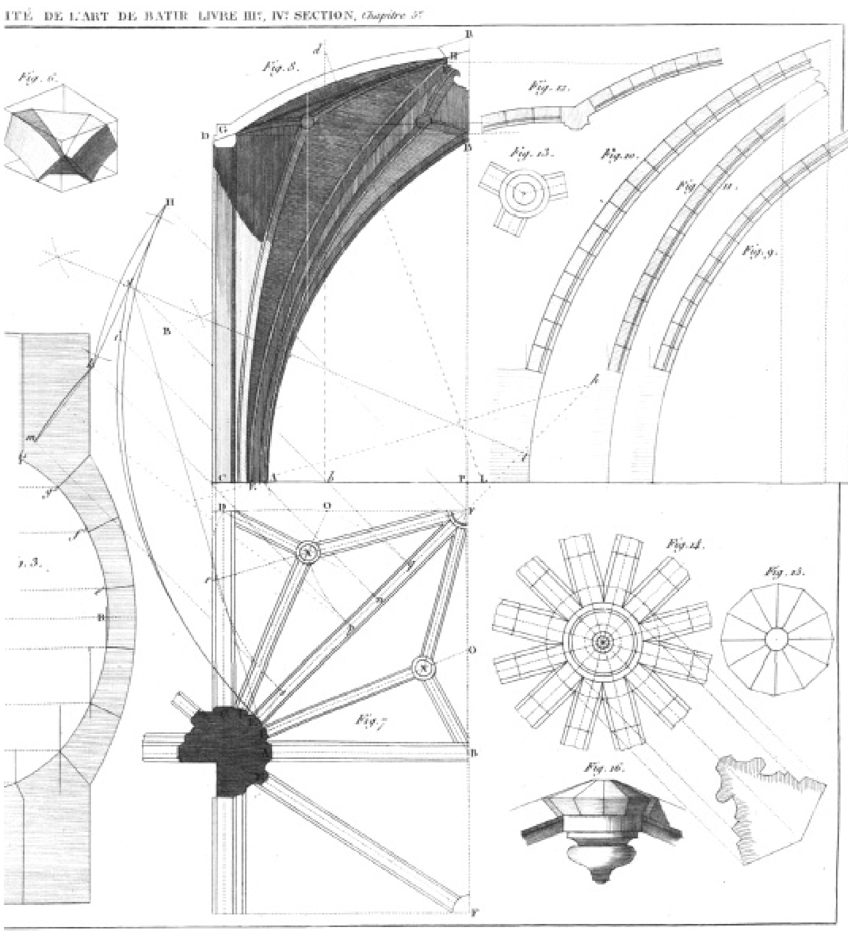


Figure 10
Vault of the church of St. Gervaise, Paris (Rondelet 1805 *L'art de bâtir*, vol 2, pl. 51)

line. The cross rib seems to have been surveyed from an scaffold, measuring vertical distances from the impost level. In any case, Gwilt drew a slightly surbased circular arch, with again the centre well below the impost plane. Pugin remarks, besides the curvature of the ribs the "inclination of the intermediate courses towards the centre of the groin" (Pugin 1823, 30). It is indeed an splendid constructive drawing.

Willis cites another two vaults from the *Examples,* published after 1828. There, throughout the whole work, Pugin interest in knowing the actual geome-

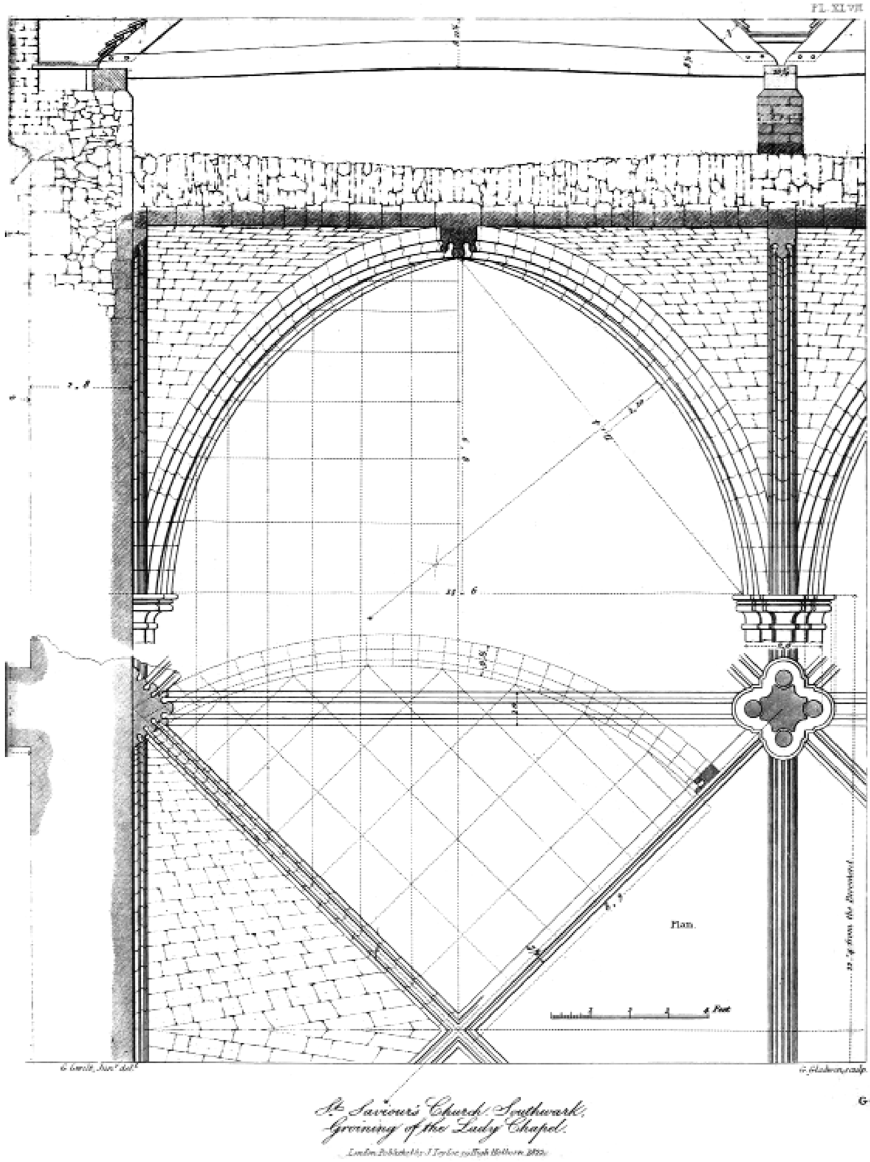
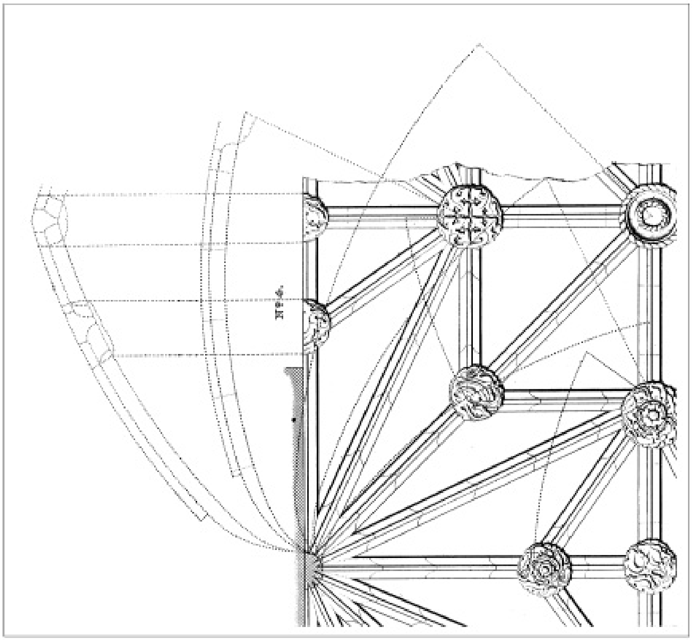


Figure 11
Vault of the Lady Chapel in St. Saviours, Southwark, surveyed and delineated by G. Gwilt (Pugin 1823, *Specimens* vol. 2, pl. 47)



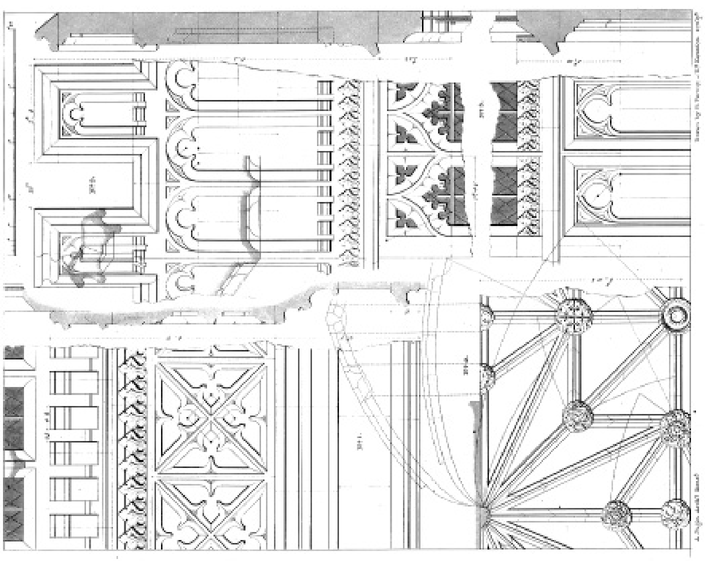


Figure 12
Gateway of Magdalene College, Oxford (Pugin 1831 *Examples* Vol. 1, Pl. 10). *Right*, enlarged view eliminating some lines to show the profile of the ribs

try of the curves of arches and groins is evident. Willis chose the most significative examples. In the gateway of Magdalene College (Oxford), Figure 12, "the ridge ribs are horizontal, and consequently the arches ribs all of the same height. Each rib consists of two arcs of circles, but the lower circle is of very small di-

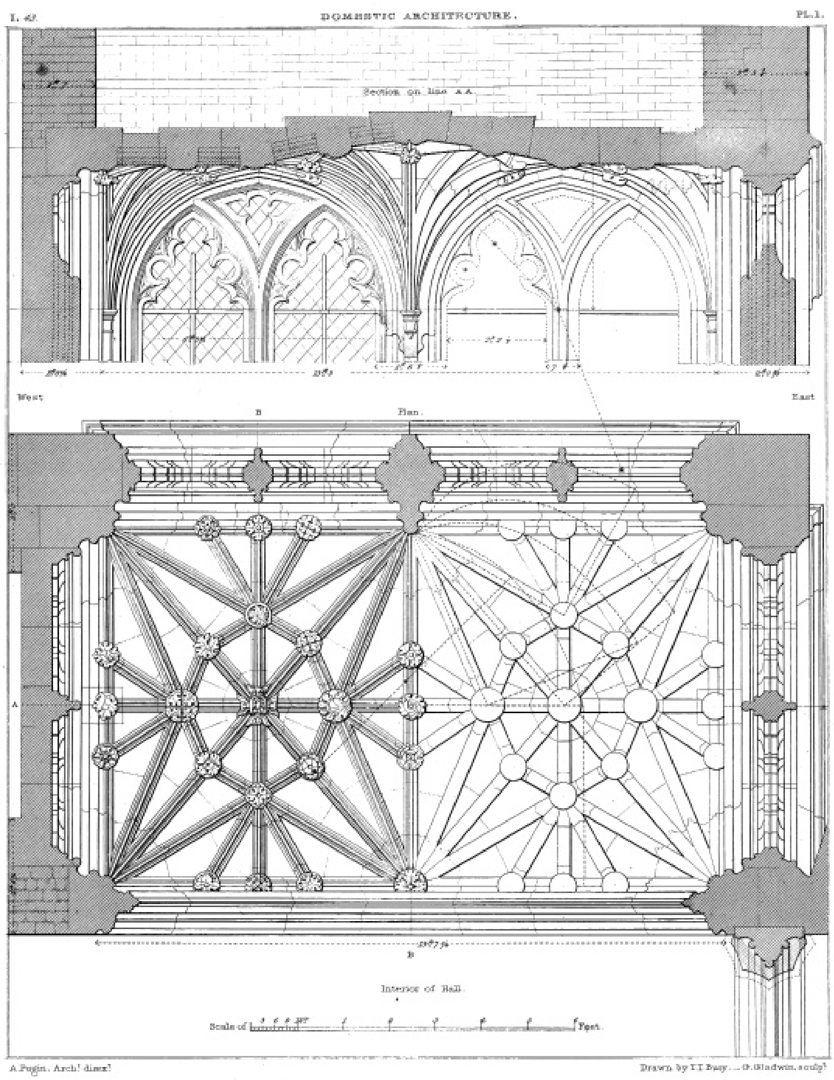


Figure 13
Vault over a bay window of Eltham Palace (Pugin 1831 *Examples* Vol. 1, Pl. 1)

ameter with respect to the upper circle, its radius being about one-ninth of the latter, and the same in all the ribs. All the upper circles of these ribs appear in this drawing to have the same radius, which is equal to the span of the transverse arch" (Willis 1842, 26).

The vault over a bay window of Eltham Palace, Figure 13, constitutes good example of study. "The ridge ribs are not horizontal, consequently in describing the curves of the arched ribs, the ridge ribs were probably first determined to give the heights of these ribs. Each rib, being half a four-centred arch, consists of two arcs of circles, the radius of the lower arc being a little less than half that of the upper arc, and this latter radius is again equal to the span of the smallest arch. These may be accidental proportions; however, the two radii are respectively the same in every rib, and consequently the different heights and spans are accommodated . . . by employing different proportional lengths of the two circles in each rib. The centre of the lower circle is in all placed on the impost level, and this I believe to be universal in four-centred arches" (27). In the plate Pugin only indicated the centres and radii of the wall ribs and of the mid-transverse rib. Again, it is evident that Willis studied the drawing with great care.

Reference list

Britton, John, Pugin, A.Ch. and .1828. *The Architectural Antiquities of Normandy*. London.

Buchanan, Alexandrina. 1994. Robert Willis and the Rise of Architectural History. Ph. D., Department of Art History. University College London.

Buchanan, Alexandrina. 2013. *Robert Willis (1800–1875) and the Foundation of Architectural History*. Woodbridge: Boydell Press, Cambridge University Library.

Derand, François. 1643. *L'architecture des voûtes ou l'art des traits et coupe des voûtes.* Paris: Sebastian Cramoisy.

Frankl, Paul. 1960. *The Gothic: Literary Sources and Interpretations Through Eight Centuries.* Princeton: Princeton University Press.

Frézier, A.F. 1737–39. *La théorie et la pratique de la coupe de pierres.* Paris: Jombert. 3 vols.

Gwilt, G. 1857. Obituary. *Journal of the British Archaeological Association*, 161–2.

Halfpenny, William. 1725. *The art of sound building, demonstrated in geometrical problems.* London: Sam Aris.

Jousse, Mathurin. 1627. *Le theatre de l'art de charpentier.* La Fleche: George Griveau.

Jousse, Mathurin. 1642. *Le secret d'architecture.* La Fleche: George Griveau.

La Hire, Philippe. 1702. Remarques sur la forme de quelques arcs dont on se sert en architecture. *Mémoires de l'Académie Royale des Sciences de Paris,* 94–97.

L'Orme, Philibert de. 1561. *Nouvelles inventions pour bien bastir et a petits fraiz.* Paris: Federic Morel.

L'Orme, Philibert de. 1567. *Le premier tome de l'architecture* Paris: Federic Morel.
Nicholson, Peter. 1828. *A popular and practical treatise on masonry and stone-cutting*. London: Thomas Hurst, Edward Chance and Co.
Nicholson, Peter. 1834. *The Builder and Workman's New Director*. London: J. Taylor.
Pugin, Augustus Charles. 1821–23. *Specimens of Gothic Architecture.* 2 vols. London: J. Taylor.
Pugin, Augustus Charles. 1831–38. *Examples of Gothic Architecture.* 2 vols. London: Printed for the author.
Rondelet, Jean. 1802–10. *Traité théorique et pratique de l'art de bâtir*. Paris: Chez l'auteur, 7 vols.
Willis, Robert. 1842. On the Construction of the Vaults of the Middle Ages." *Transactions of the Royal Institute of British Architects* 1: 1–69.
Willis, Robert. 1844. *Architectural Nomenclature of the Middle Ages*. Cambridge: At the University Press.

ISBN: 978-84-9460-000-5